THE PRINCIPLES OF SOIL SCIENCE

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BY

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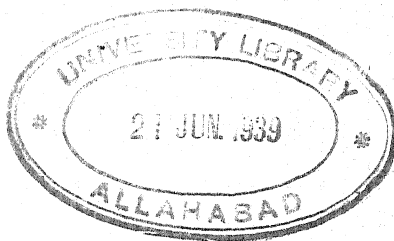University of Budapest

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FOREWORD

PROFESSOR DE SIGMOND'S investigations on soils have long been familiar to English and American experts, and on two occasions already he has given account of the branch with which his name is most closely associated by English-speaking people—the reclamation of alkali soils. But those who know him best always knew that his knowledge and experience covered the whole range of soil science and wherever he has intervened in a soil discussion he has always illumined it. He is one of the best known experts on soil, and he has the advantage that his native land, Transylvania, and his adopted country, Hungary, are both rich in important soil types not commonly familiar to Western European students.

The main theme of the book (published some years ago in longer form in Hungarian) is the presentation and discussion of the system of soil classification already known internationally by the author's name, but never before described in detail in an English publication, consequently it has not received from English and American investigators the careful scrutiny which it merits as a positive contribution towards the advancement of soil science. No harm can result if some readers find themselves in disagreement with the author on making first acquaintance with the details of his system. Every country possesses certain soil types not found elsewhere; certain English soils, for example, do not easily fit into Professor de Sigmond's system, and certain Hungarian soils fit into no English system. The comprehensive classification here proposed, based essentially on the chemical composition of the soil, is not intended to be final, but it satisfactorily fills many gaps in other systems, and leads us a considerable step further towards the goal of every soil taxonomist—a universal classification based on strictly scientific principles.

Every country of the civilised world is now taking stock of its agricultural possibilities for the double purpose of increasing its natural wealth by greater output from the land, and of finding how far it could go in producing sufficient food to maintain its people so as to be independent of outside supplies. This has brought into prominence the need for assessing natural soil resources, and in every country soil surveys of one kind or another are now being made. Fortunately the

International Society of Soil Science affords a common meeting ground for friendly discussion by the soil experts of the different countries, with the result that the work is done on lines which, if not always identical, at any rate ensure that the results shall be comparable. The investigations now being made on soil are therefore not only serving the countries immediately concerned, but they are helping also all students of soil science wherever they may be and on whatsoever problems they may be engaged. Professor de Sigmond has put us under a debt of gratitude by summarising his own wide experience and discussing in the light of his own knowledge the work that is being done by others.

E. J. RUSSELL.

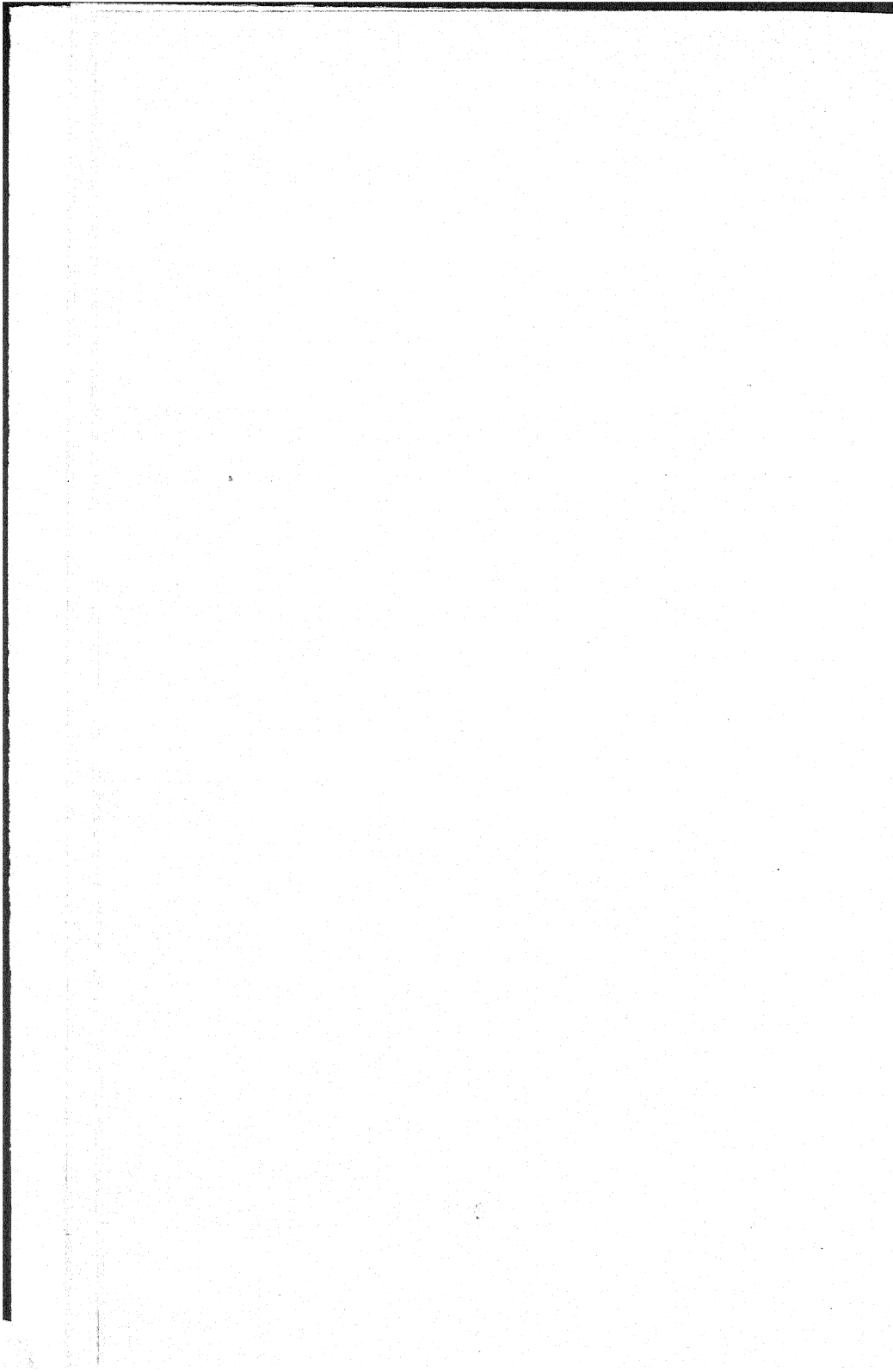ROTHAMSTED EXPERIMENTAL STATION,
       HARPENDEN.

AUTHOR'S PREFACE

THE English literature of soil science is so rich that it may seem presumptuous on the part of a foreigner to suggest that his own work can contribute something more to the work of English or English-reading soil experts. Nevertheless, since my monograph on "Hungarian Alkali Soils" has been published in English by the University of California (in 1927), and since I have published my "General Soil System" in English, my English correspondence has grown so considerably that in some way I do not feel quite a foreigner in English soil work.

This encouraged me to undertake the English translation of my Hungarian book on Soil Science. The aim of the latter was to give an almost full outline of the present state of Pedology. The whole book is divided into four parts: Genetics, Agronomy, Systematics and Cartography. As, however, English soil literature is so rich, especially in Soil Physics and Microbiology, in cutting down my original work I have felt entitled to leave out the sections of Part II. on Soil Physics and Soil Microbiology and all those details which possess mere local interest or which have been dealt with thoroughly in other English works.

My particular thanks are due to Professor A. B. YOLLAND, Ph.D., who undertook the hard work of the translation with so much enthusiasm and zeal. My cordial thanks are due also to Mr. G. V. JACKS, of the Imperial Bureau of Soil Science, who has acted as editor of the translations. I am particularly indebted to Mr. G. H. FREEMAN (Messrs. Thomas Murby and Co.), whose sympathetic co-operation has enabled me to put through the English publication of this book. I wish to record here also my thanks to all my young colleagues, A. ARANY, E. BECKER, J. DI GLERIA, E. HORVÁTH, L. KOTZMANN, L. TELEGDY-KOVÁTS and F. ZUCKER, as assistants or co-workers.

Finally, I feel very much honoured by Sir JOHN RUSSELL, Director of the Rothamsted Experiment Station, having been kind enough to write a Foreword to this book.

<div align="right">A. A. J. DE SIGMOND.</div>

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INTRODUCTION

SOIL SCIENCE AND ITS FIELD

SOIL science (pedology) gathers into a scientific system what we know concerning that peculiar product of nature—the soil. For a long time soil science was not regarded as an independent branch of natural philosophy, but as an applied science—*e.g.*, as a branch of agriculture. The first to try to liberate soil science from this position was the German geologist Frederick Augustus Fallou, who, however, by basing his soil classification upon geological-petrographic principles unconsciously subordinated pedology to geology. However, it soon became evident that the peculiarities of the several soil types could not be explained satisfactorily either by a geological or by a petrographic origin. Undoubtedly it appears at first sight natural that soil—which is the geologically youngest and weathered outer cover of the solid surface of the earth—should in principle be just as much a part of the history of our globe as are the other geological formations. In this broad sense Ramann himself was prepared to admit·that soil science is a branch of geology which may rightly be called " geology of the upper crust of the earth." Ramann defined soil as " the outer weathered layer of the solid crust of the earth." Earlier still, in 1901, Yarilov, the Russian pedologist, had given the following definition of the inter-relation of geology and pedology: " Geology treats of the dead part of our globe, while soil science deals with the ever-changing, living earth-cover which is exposed to the constant changes brought about by the radiation of the sun, by atmospheric precipitations and by living organisms." There is indeed a real difference between the dead masses of rock and the ever-changing soil, which may rightly be called " living." Petrography and mineralogy seem more akin to pedology than historical and dynamic geology, for the parent material of most soils is rock. To-day petrography is concerned not only with the origin, but also with the weathering of rocks.

Yet petrographers investigate the weathering process from a different point of view from pedologists, who are interested in those transitory states and changes of rock which cannot be defined by petro-graphic or mineralogical methods. Rocks may be classified according to their component minerals, whereas the clearly definable minerals in

soils are mostly of no importance for the purpose of determining the soil type. This is due to the soil-forming rock being only one, and very often by no means the dominant factor in soil formation.

Towards the end of the last century a Californian soil scientist, Hilgard, and the Russians Docuchaiev and Sibirtzev, independently proved that climate plays a very important rôle in soil formation. In Russia an entirely new school began to work on these lines.

When in 1909 (April 14-24) the Hungarian Geological Institute celebrated the fortieth anniversary of its establishment, the soil scientists of the world were invited to a conference in Budapest; that was the origin of the First International Agro-geological Conference, and the above date was an important turning-point in the development of pedology as a science. Thus soil science liberated itself from the leading-strings of other sciences and practice; the object of pedological research was recognised to be the soil itself as a natural product; a knowledge of soils is the sole object of pedology, as a knowledge of minerals is the sole object of mineralogy. Geology, petrography, mineralogy, chemistry, physics, plant physiology, plant biology, bacteriology and to some extent zoology are just as much auxiliary to pedology as crystallography, chemistry, physics, etc., are auxiliary to mineralogy. Whereas formerly pedological research was merely the handmaid of other sciences, to-day soil science itself has been divided into physical, chemical, biological, physiological, genetic-cartographical and applied sections, which are all, however, occupied primarily in studying the soil as a peculiar natural product. This division of soil science was already in vogue at the Fourth International Pedological Conference held in Rome, where in 1924 the International Society of Soil Science, containing the six sections enumerated above, was founded. For everything connected with the origin or formation of soils— everything associated with the chemical, physical and biological properties of soils or illustrating the changes of those properties— must be the subject of pedological research; and a scientific system of soil classification has resulted from that research. Soil cartography is in reality the fixation of soil types according to their distribution in nature, and belongs to theoretical soil science, unless it enters into details and is local in character. Detailed—e.g., agricultural—soil maps are rather the work of applied soil science.

We must not, however, imagine that having become an independent science has deprived pedology of any of its practical importance. On the contrary, its practical importance and its efficiency have materially increased, and even during the short period that has elapsed since a beginning was made with the scientific study of soils, many practical results not dreamed of before have been obtained.

Apart from entirely new practical lines of work having developed in the milieu of pure science, certain earlier lines of practical research have been given a wider and a purely scientific application. The phenomena of soil leaching and soil absorption had for instance been

long familiar, though they had been investigated only as a means of showing the extent to which valuable plant foods were leached out. Soil science, however, deals with these phenomena on a much wider and purely scientific basis, and to-day they constitute one of the most interesting chapters of pedological science, and have already led to important practical results—enabling us, for instance, to ascertain the origin, possibilities and methods of reclamation of alkali soils.

The fact that pedology has risen to the dignity of an independent natural science has in no way impaired its connection with the other natural sciences. On the contrary, all kindred sciences have gained by the concentration in a scientific system of all our pedological knowledge. Previously this knowledge was scattered about the whole field of scientific literature, a fact which made it extremely difficult to find references.

The field of soil science embraces both the purely scientific and the practical applications of pedology, for which reason we may divide the material into two large groups—viz., general and applied pedology. The present work deals only with general pedology.

I have divided the material of general pedology into four parts. The first part deals with the origin of soil and with the soil-forming factors and phenomena connected therewith: this part may be called genetics. The second part deals with the physical, chemical and biological properties of soils—i.e., with the scientific criteria enabling us to characterise soils exactly and scientifically: this part is therefore called agronomy. The third part deals with the soil system (systematics) and the characterisation of soil types by means of an entirely new, general soil system. The fourth part deals with the principles, character and purposes of soil cartography and schematic soil diagrams.

In order to define accurately the field of soil science, it is necessary to give an exact definition of what we mean by " soil." Most pedologists still insist on briefly defining soil as the outer weathered layer of the solid earth-crust. In the light of our present pedological knowledge this definition is, however, inadequate. For, though the soil is certainly the outer layer of the solid earth in contact with the air and more or less weathered, that is not all that can be said about the soil. Whereas rocks are regarded as the symbols of stability and solidity, the soil is the soft bed of seeds and plant roots, the support and the food of the vegetable world and the home of change. Rocks are dead mineral substance, while the soil teems with life and is the source of all new vegetation. Although soil science is not confined to the relations existing between cultivated soil and agricultural plants, nevertheless one of the outstanding properties of soils is that they are, or may become, the carriers of higher vegetation. Barren saline soils, for instance, often prevent every kind of plant growing because the salt concentration is too high, but when a sufficient proportion of the salts has been removed certain kinds of vegetation are able to exist. Similarly, the soil of barren deserts is plantless because of the lack of humidity, but

wherever any springs rise or artificial irrigation is employed, the soil very soon becomes the source of luxuriant vegetation. For that reason Yarilov was right when he characterised soil as a constantly changing, living earth-cover exposed to continual changes due to the effect of insolation, precipitation and living organisms.

Much the same definition was given by Hilgard,* who describes the soil as the more or less loose and crumbling part of the outer earth-crust in which plants are able to strike root, deriving therefrom their food and all other conditions essential to their growth.

Both definitions show clearly the close relation between soils and living organisms—in particular the plant world. We are, indeed, entitled to say that soils belong to the biosphere (pedosphere)—i.e., to that outer layer of the earth in and on which organic life exists—in contrast to the lifeless lithosphere, the outermost but dead crust of the earth. But the biosphere includes also fresh and salt water and the mud of lakes and seas. This latter is physically very closely related to, and in many cases hardly distinguishable from soil, being rich also in living organisms; but it differs from soil in that it is covered with water, whereas soils are in immediate contact with the atmosphere. Both fresh and salt water differ from soil in their state of aggregation and by the circumstance that, whereas the bulk of fresh and salt water consists of water or of substances dissolved in water (i.e., in molecular dispersion), in soils—even where we find 40-50 per cent. of water—the bulk of the substances are not in solution and are indeed insoluble in water; indeed, in soils it is the water rather than the mineral matter which is in the dispersed state.

In volume and quantity the pedosphere is relatively insignificant when compared with the other spheres of the earth, but it is the source of all living existence. Soils are thus intermediate between the dead and the living world, being the prime source and carrier of all life. As natural products, they constitute an integral component of the solid part of the earth; and therefore—and for that reason only—come within the sphere of geology, as may also the atmosphere. According to Docuchaiev, the various soil zones are natural products which have assumed a character independent of the parent rock as a result of the effect of the atmosphere and biosphere on the lithosphere. The formation and existence of soils depend upon special circumstances and factors which may be called collectively soil-forming factors. These factors are so characteristic of the several soil types that if we desire to obtain an exact idea of what soils are, the best way is to study soil genetics—i.e., the origin and formation factors of soils. Upon these soil-forming factors depend the peculiar structure of the soil and the physical, chemical and biological properties which differentiate it from both the dead and the living worlds. In the same way as the pedosphere lies between the lithosphere and the atmosphere, so also it may be said to be wedged between the living and the dead

* See HILGARD, DR. E. W.: " Soils," 1910, p. xxi.

mineral worlds, which it connects and links together. It is in the soil that inorganic substances are transformed into living organisms, and dead organic matter also changes back into inorganic compounds. The soil is the cradle and the burial-place of all life, proving the truth of the Christian teaching " Dust thou art and to dust returnest."

If we summarise all that has been said above with respect to the term " soil," we see at once that the earlier definition that the soil is the outer weathered layer of the solid earth-crust does not satisfy the requirements of present-day soil science. Soil is a discrete natural product differing from both the dead mineral world and the living organic world, lying on the boundaries of the lithosphere and the biosphere and connected with both, uniting them and obtaining its raw materials from them; it is the product of special genetic factors which determine and continuously direct the physical, chemical and biological phenomena and characteristic properties of the soils, thus making them the cradle of continuous organic life and the burial-place of dead organic matter.

The soil is the scene of constant changes and transformations. According to Stebutt* it is a dynamic system, in contrast to the static systems represented by rocks and minerals, and an outstanding feature of modern pedology is its recognition of the soil's dynamic nature. If we wish to understand a soil, we cannot consider only its present condition, which merely presents a section of the dynamic changes. To appreciate the character of such a dynamic system we must study its past history as well as its present and be in a position to foretell, or at least to surmise, its future development. Marbut was right in principle when he said† that the determination of soils cannot be based upon the factors or causes of which the soils themselves are the results. Yet, to some extent the genetic factors are the character of a soil, seeing that they have unceasingly influenced its development.

I. O. Veatch gives the term " soil " a far wider meaning when he says that all media capable of bearing or carrying natural vegetation may be described as " soils." In his opinion, for instance, living peat is also soil, because living vegetation is found in or on it. Veatch's definition is a very wide one, including as it does both water and solid rocks. We might go even further and include under the name of " soils " everything offering support or food. Soil science, however, does not include the term " soil " in this wide sense in its field of study.

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* STEBUTT, A.: " Lehrbuch der allgemeinen Bodenkunde," Preface, p. iv.
† " Proc. and Papers of the First Int. Congress of Soil Science," Washington, D.C., June 13-22, 1927, V. Comm., p. 6.
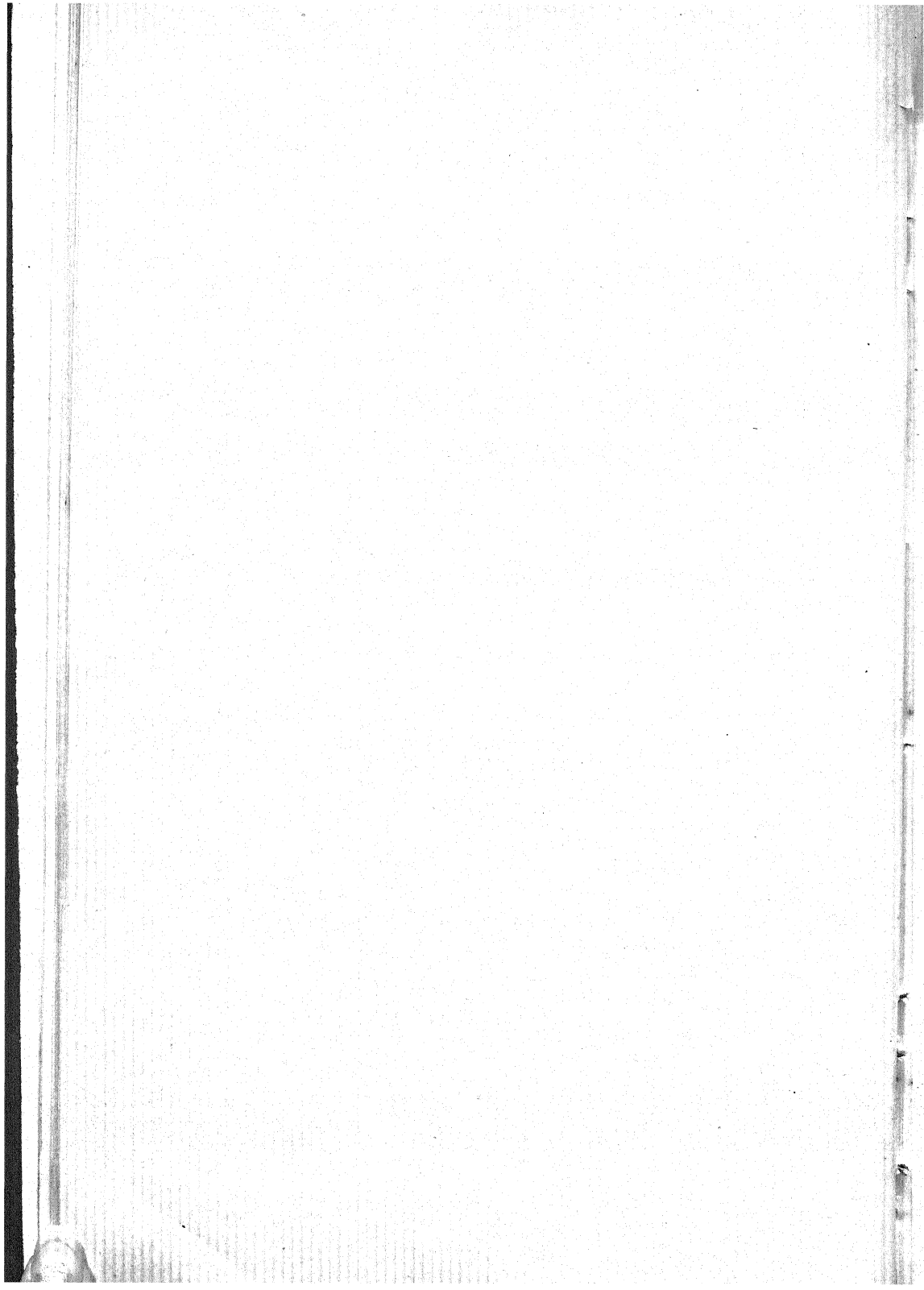
PART I

GENETICS

THE study of soil genetics embraces the raw materials from which soils are formed, the factors converting them into soil, and the pedogenic processes which lead to the development of distinct soil types according to the conditions under which soil formation takes place.

CHAPTER I

GEOLOGICAL AND PETROGRAPHIC SOIL-FORMING FACTORS

PETROGRAPHY is in reality a specific branch of geology, and it might seem sufficient to speak of the geological origin of soils. However, since various rocks form the raw materials of soils, it is better not to confine ourselves to general geological factors but to take petrographic phenomena into account as well.

The first stage in soil formation is the natural disintegration of solid rock. There are indeed original rocks—*i.e.*, geological formations—which do not consist of hard and dense material. Such rocks are, for instance, loess, gravel, sand, peat, etc. But soils may be formed also from solid rocks, and the first stage in soil formation must be regarded as the pulverisation of solid rocks. The hard outer crust of the earth in contact with the atmosphere sooner or later disintegrates and crumbles—this weathering process being accompanied by changes which are partly physical and partly chemical. Hence science speaks of physical and chemical weathering, although in nature the two are so closely interwoven that it is often extremely difficult to distinguish between them. Both kinds of weathering are complicated by biological factors, but the dominant influence in weathering is either physical or chemical, and determines the nature of the weathering product, which usually depends upon climatic conditions. According to Ramann, the surface of the earth may be divided into regions characterised by the weathering conditions prevailing in them.*

The geological and petrographic soil-forming factors may be grouped as follows:

1. *Dynamic Factors.*—(*a*) Physical weathering; (*b*) erosion; (*c*) river, lake and sea deposits; (*d*) glacial formations; (*e*) sub-aerial dust; (*f*) wind deposits.

* RAMANN: " Bodenkunde," 3rd Ed. (1911), p. 8.

2. *Mineral-Chemical Factors.*—(a) Soil-forming rocks; (b) minerals; (c) chemical weathering.

The dynamic factors, which are known to us from geology, will not be discussed here, though they also figure frequently in soils. We are more concerned with the mineral-chemical factors, with which we shall deal in detail.

(a) *Rocks and Minerals Important as the Parent Materials of Soils.*—The outermost strata of the earth are composed chiefly of alumino-silicates (Si-Al=Sial zone). The composition of this stratum to a depth of some 16 kilometres below the surface has been determined by CLARKE* and WASHINGTON,† as shown in Table I.‡

TABLE I

AVERAGE CHEMICAL COMPOSITION OF THE EARTH'S CRUST
16 KILOMETRES DEEP

Percentage of Elements.			*Percentage of Oxides.*		
O	.. .. ..	46·46	SiO_2	.. .. ..	59·08
Si	.. .. ..	27·61	Al_2O_3	.. .. ..	15·23
Al	.. .. ..	8·07	Fe_2O_3	.. .. ..	3·10
Fe	.. .. ..	5·06	FeO	.. .. ..	3·72
Mg	.. .. ..	2·07	CaO	.. .. ..	5·10
Ca	.. .. ..	3·64	MgO	.. .. ..	3·45
Na	.. .. ..	2·75	Na_2O	.. .. ..	3·71
K	.. .. ..	2·58	K_2O	.. .. ..	3·11
Ti	.. .. ..	0·62	H_2O	.. .. ..	1·30
H	.. .. ..	0·14	TiO_2	.. .. ..	1·03
P	.. .. ..	0·12	MnO	.. .. ..	0·12
C	.. .. ..	0·09	CO_2	.. .. ..	0·35
Mn	.. .. ..	0·09	P_2O_5	.. .. ..	0·29
S	.. .. ..	0·06	Cl	.. .. ..	0·05
Cl	.. .. ..	0·05	SO_3	.. .. ..	0·03
Br	.. .. ..	0·04	C	.. .. ..	0·04
F	.. .. ..	0·03	Others ..	.. ..	0·29
Others ..	.. ..	0·50			
		100·00			100·00

It will be seen that 75-80 per cent.—*i.e.*, far the greater part—of the material consists of O, Si and Al, or, more precisely, of SiO_2 and Al_2O_3. If we include the hydrosphere and the atmosphere—the gravimetric ratios of which are 6·91 per cent. and 0·03 per cent. respectively, that of the lithosphere being 93·06 per cent.—and take their average composition, we obtain the values shown in Table 2.§

* CLARKE, F. W.: "The Data of Geochemistry," 5th Ed., 1924 (U.S. Geol. Survey Bull.), p. 770.
† WASHINGTON, H. S.: "The Chemistry of the Earth's Crust" (U.S. Geol. Survey, Paper 14), and CLARKE and WASHINGTON (*ibid.*, Paper 127).
‡ BLANCK, E.: "Handb. d. Bodenlehre," Vol. I., p. 88.
§ BEHREND, F., and BERG, G.: "Chemische Geologie," pp. 4-5.

TABLE II

CHEMICAL COMPOSITION OF THE KNOWN PART OF THE EARTH

	Igneous Rocks (88.41%).	Slate (3.72%).	Sandstone (0.70%).	Limestone (0.23%).	Hydrosphere (6.91%).		Atmosphere (0.03%).	
SiO_2 ..	59·12	58·11	78·31	5·19	H_2O	96·24	N	75·77
Al_2O_3 ..	15·34	15·40	4·76	0·81	Cl	2·07	O	22·69
Fe_2O_3..	3·08	4·02	1·08 ⎫		Na	1·14	A	1·23
FeO ..	3·80	2·45	0·30 ⎭	0·54	Mg	0·14	H_2O	0·27
MgO ..	3·49	2·44	1·16	7·89	Ca	0·05	CO_2	0·04
CaO ..	5·08	3·10	5·50	42·57	K	0·04		
Na_2O ..	3·84	1·30	0·45	0·05	SO_4	0·27		
K_2O ..	3·13	3·24	1·32	0·33	Br	0·008		
H_2O ..	1·15	4·99	1·63	0·77	C	0·008		
CO_2 ..	0·102	2·63	5·04	41·54	I	0·00018		
TiO_2 ..	1·050	0·65	0·25	0·06				
ZrO_2 ..	0·039							
P_2O_5 ..	0·299	0·17	0·08	0·04				
Cl ..	0·048			0·02				
F ..	0·030							
SO_3 ..		0·65	0·07	0·05				
S ..	0·052			0·09				
$(CeY)O_3$ ..	0·020							
Cr_2O_3 ..	0·055							
V_2O_3 ..	0·026							
MnO ..	0·124			0·05				
NiO ..	0·025							
BaO ..	0·055	0·05	0·05					
SrO ..	0·022							
Li_2O ..	0·007							
Cu ..	0·010							
Zn ..	0·004							
Pb ..	0·002							
C ..		0·80						

This table shows that igneous rocks compose the bulk (95 per cent.) of the known part of the lithosphere, only 5 per cent. consisting of sedimentary rocks (4 per cent. being slates, 0·75 per cent. sandstone and 0·25 per cent. limestone). It is also of interest to know that the quantitative distribution of the principal mineral groups in the igneous rocks (95 per cent.) is as follows:

felspars	59·5 per cent.
amphiboles and pyroxenes	16·8 ,, ,,
quartz	12·0 ,, ,,
micas	3·8 ,, ,,
other minerals	7·9 ,, ,,

100·0 per cent.,

the bulk of the material being supplied by the first three groups.

TABLE III

CHEMICAL COMPOSITION OF SOME WELL-KNOWN FELSPARS

Old Nomenclature.	Per Cent.	New Nomenclature.	Per Cent.	Gr. Equiv.	Sum of Gr. Equiv.	Percentage of Gr. Equiv.
Orthoclase (Adularia)						
K_2O	14·8	K^I	12·29	0·3148		21·80
Na_2O	1·3	Na^I	0·96	0·0417		2·89
CaO	0·3	Ca^{II}	0·21	0·0105		0·72 } 100
Al_2O_3	18·4	Al^{III}	9·80	1·0769	1·4439	74·59
SiO_2	64·5	$Si_3O_8^{IV}$	76·41	1·4439	1·4439	100·00
Total ..	99·3		99·67			
Albite						
Na_2O	11·04	Na^I	8·19	0·3564		20·21
CaO	0·32	Ca^{II}	0·22	0·0110		0·73
MgO	0·03	Mg^{II}	0·02	0·0017		0·11 } 100
Al_2O_3	19·53	Al^{III}	10·40	1·1428	1·5119	78·95
SiO_2	68·75	$\{ Si_3O_8^{IV}$ / $SiO_2 \}$	80·01 / 0·81	1·1519	1·5119	100·00
Total ..	99·67		99·65			
Oligoclase						
K_2O	0·8	K^I	0·66	0·0169		0·95
Na_2O	9·7	Na^I	7·20	0·3133		17·66
CaO	2·8	Ca^{II}	2·00	0·1003		5·65 } 100
MgO	0·4	Mg^{II}	0·24	0·0200		1·13
Al_2O_3	22·6	Al^{III}	12·04	1·3231	1·7736	74·61
SiO_2	64·3	$\{ Si_3O_8^{IV}$ / $SiO_4^{IV} \}$	69·90 / 10·40	1·3208 / 0·4528	1·7736	74·47 / 25·53 } 100
Total ..	100·6		102·44			

Andesine

K_2O	0·08		K^I	0·07	0·0017	0·09
Na_2O	7·28		Na^I	5·40	0·2351	11·16
CaO	7·25		Ca^{II}	5·18	0·2596	13·31
Al_2O_3	25·35		Al^{III}	13·51	1·4842	75·54 } 100
SiO_2	60·48		$Si_3O_8^{IV}$	50·12	0·9472 } 1·9806	47·80
			SiO_4^{IV}	23·73	1·0334 } 1·9806	52·20 } 100
			SiO_2	2·43		
Total	100·44	··		100·44		

Labradorite

K_2O	1·13		K^I	0·94	0·0241	1·04
Na_2O	4·50		Na^I	3·94	0·1453	6·27
CaO	11·42		Ca^{II}	8·16	0·4090	17·65
Al_2O_3	29·71		Al^{III}	15·83	1·7345	75·04 } 100
SiO_2	54·19		$Si_3O_8^{IV}$	35·86	0·6776 } 2·3179	29·23
			SiO_4^{IV}	37·66	1·6403 } 2·3179	70·77 } 100
Total	100·95	··		101·79		

Bytownite

K_2O	0·38		K^I	0·315	0·0081	0·33
Na_2O	2·82		Na^I	2·093	0·0911	3·71
CaO	14·24		Ca^{II}	10·171	0·5098	20·76
MgO	0·87		Mg^{II}	0·522	0·0436	1·77
Fe_2O_3	0·80		Fe^{III}	0·560	0·0200	0·81
Al_2O_3	30·45		Al^{III}	16·233	1·7827	72·62 } 100
SiO_2	47·40		$Si_3O_8^{IV}$	20·999	0·3928 } 2·4553	16·16
			SiO_4^{IV}	47·263	2·0585 } 2·4553	83·84 } 100
Total	96·96	··		98·146		

Anorthite

CaO	18·31		Ca^{II}	13·08	0·6556	23·94 } 100
Al_2O_3	35·57		Al^{III}	18·95	2·0024	76·06
SiO_2	45·06		SiO_4^{IV}	62·86	2·7380 } 2·7380	100
			SiO_2	4·05		
Total	98·94	··		98·94		

The various known minerals have for long been grouped according to their chemical composition; recently the method of petrographic grouping on the basis of chemical composition has been gaining ground. I cannot deal here in detail with the chemical composition of the more important rock-forming minerals,* and will merely point out that it is usually still expressed in the old dualistic manner. For instance, gypsum in a pure state has the formula $CaSO_4 2H_2O$, but in modern textbooks its chemical composition is still expressed as 32·5 per cent. CaO, 46·6 per cent. SO_4 and 20·9 per cent. H_2O, although 23·3 per cent. Ca, 55·8 per cent. SO_4 and 20·9 per cent. water of crystallisation would be more correct. Similarly, while the formula of adularia or sanidine is $KAlSi_3O_8$, the theoretical composition is expressed as 64·7 per cent. SiO_2, 18·4 per cent. Al_2O_3, 16·9 per cent. K_2O— though 76·3 per cent. Si_3O_8, 9·7 per cent. Al and 14·0 per cent. K would be more correct.

It would be even more correct to convert these values into equivalents and then calculate the percentages of the positive constituent elements. We then find that pure potassium felspar contains 25 per cent. of potassium and 75 per cent. of aluminium equivalents. Table III shows the chemical composition of some felspars.†

The chemical composition of felspars shows that generally speaking trivalent metals (Al and Fe)—calculated as equivalents—comprise about 75 per cent. of the positive elements, the remainder (25 per cent.) consisting of univalent and bivalent metals. The molecular ratio is given by the formula $Al_2O_3 : RO$ (or R_2O)$=1 : 1$.

The form of silicic acid has been calculated by assuming that the alkali metals are combined in the mixed felspars with trisilicic acid $(Si_3O_8^{IV})$ and calcium with orthosilicic acid (SiO_4^{IV}).

Igneous (including also pyroclastic) rocks are compounds of various minerals; consequently, their composition cannot be expressed by the stoichiometric method employed above. Yet it cannot be said that their composition is entirely random, as may be seen from the fact that whereas formerly rocks were classified according to their mineral composition, geological age and physical structure, today it is becoming more and more usual to group them on the basis of their chemical composition. I do not propose to deal exhaustively with these petrographic systems.‡

We have now to ask ourselves what is the nature of the connection proved to exist between rocks and the soils derived from them. All we can answer is that the effect exerted by rocks upon soil formation varies very considerably. There are cases in which the character of soils differs in accordance with the character of the parent material— particularly in places where the other soil-forming factors have for

* Given briefly in BLANCK, E.: "Handb. d. Bodenlehre," Vol. I., pp. 90-111.
† SIGMOND, A. A. DE: Intern. Mitt. für Bodenkunde, Vol. II. (1923), Nos. 2-3.
‡ For details, see BEHREND and BERG, "Chemische Geologie," pp. 56-62, and BLANCK, E., "Handbuch der Bodenlehre," Vol. I., pp. 114-134.

some reason or other not been able to assert themselves sufficiently to counteract the influence of the original rock. Ramann, for instance, has pointed out that in certain parts of Germany the quality of the soil corresponds exactly to the character of the parent rocks. Delage and Lagatu,* after mineralogically examining various alluvial soils of local formation in the South of France, showed that the soils thus formed have a composition so absolutely similar to that of the parent rock as to suggest their being detritus of the same rock rather more finely dispersed.† And by chemical analysis Ballenegger has shown that the composition of the " nyirok " soil of the Tokay district in Hungary is remarkably similar to that of the parent material.‡ This would seem to contradict the views of the Russian school and of other scientists according to which the same soil type may be formed from rocks of very different character where climatic factors are dominant. The contradiction, however, is only an apparent one, since relative potency of the various soil-forming factors varies with changing conditions. The predominant factor may change, for ultimately all factors will interact to form the soil.

Finally, we may say that *the original unweathered minerals usually constitute the least active part of the soil, while the chemically weathered part has a particular significance in soil formation and the development of soil character.*

(b) *Factors influencing the Chemical Weathering of Minerals and Rocks.*—It should be noted that the term " chemical weathering " includes only the chemical changes of rocks induced by atmospheric influences. The term does not therefore include post-volcanic influences, volcanic exhalations, etc.

The most effective atmospheric factor is liquid water. Ice and snow are inert and do not belong here. The presence of liquid water is a *sine qua non* of all chemical weathering. We may add also the materials dissolved in water and which originate from the atmosphere or are formed in the soil itself—*e.g.*, nitric acid, ammonia, oxygen, carbonic acid, chlorides, sulphates, humus materials. The most important of these materials in their effect are carbonic acid and oxygen.

1. *Water as a Weathering Factor.*—In chemical weathering water acts either as a solvent or as an agent of decomposition. The action of water as a solvent is confined mostly to gases and solids; solution of liquids is negligible. In connection with the dissolution of gases we must remember that atmospheric precipitations are continuously in contact with the air during their long descent to the earth, and

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* DELAGE and LAGATU: "Constitution de la terre arable" (Montpellier, 1905).

† For details see 'SIGMOND, A. A. DE: "Über die Verwitterung der Böden und die Nützlichkeit der mineralogisch-petrographischen Bodenanalyse" (Földtani Közl., Vol. XXXVI., 1908), pp. 220-230.

‡ BALLENEGGER, R.: "A tokajhegyaljai nyiroktalajról" (Földtani Közlem., Vol. XLVII., 1917, p. 20).

after reaching the soil remain in contact with the soil atmosphere for a considerable time and over a large surface. Nernst* has shown that when water comes into contact with several gases, the amount of each dissolved is the same as if the others were not present. The solubility of gases varies considerably, N, O and CO_2—the gases involved in weathering—being relatively insoluble. Of these CO_2 and O are the most soluble. Water also dissolves some ozone and ammonia from the air.

The solubility in water of the solid materials varies considerably; pure water scarcely dissolves the rock-forming minerals at all, but some minerals (e.g., $CaCO_3$ and $MgCO_3$) are highly soluble in water containing carbonic acid, with which they form easily soluble bicarbonates. This is usually regarded as pure solution, though actually solution is accompanied by chemical reaction. Similarly, carbonic acid converts slightly soluble phosphates into less insoluble compounds. Finally, recent work has shown that *even the least soluble minerals*—e.g., *silicates*—*dissolve slightly in pure water and only afterwards are decomposed by water or carbonic acid or other material dissolved in the water.*

We must therefore differentiate between the action of water as a solvent and as a decomposing agent; decomposition is affected either by the water itself or by means of dissolved substances.

2. *Electrolytic Dissociation of Water.*—Water itself only slightly possesses the property of dissociating into its free ions. According to Kohlrausch and Heydweiler, ten million litres of pure water at a temperature of 22° C. contain 1 gramme of H ions and 17 grammes of OH ions, equal to 1 gramme-molecule of water. This so-called electrolytic dissociation of water increases considerably with rise in temperature. The reaction may be expressed by the following equation:

$$H_2O \rightleftharpoons H\cdot + OH',$$
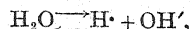
where H· represents hydrogen ions charged with positive electricity, and OH' negatively charged hydroxyl ions. Electrolytic dissociation follows the law of Mass Action—*i.e.*:

$$\frac{[H\cdot] \cdot [OH']}{[H_2O]} = K.$$

The brackets represent concentrations of molecules or ions calculated as gramme-molecules in 1 litre of water. Since water breaks up into ions only to a very slight extent $[H_2O]$ may be regarded as a constant. K is also a constant at any given temperature, and consequently we may transfer the $[H_2O]$ to the right side of the equation. The resultant constant $[H_2O].K$ is designated K_w, the " dissociation

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* Nernst, W.: Zeitschrift phys. Chem., Vol. VIII. (1891), p. 110.

constant of water." At a temperature of 22° C. it amounts to roughly 10^{-14}; in other words, 1 litre of water contains 10^{-7}—*i.e.*, 0·0000001 gramme-ion of H· or OH'. This shows that the molecular quantity of undissociated H_2O is relatively so large that it may be regarded as constant. The fact that K_w changes with change of temperature is due to the $[H_2O]$ value being more sensibly affected by the change of temperature than K.*

Water occupies a quite peculiar position among chemically homogeneous liquids. What interests us here are its peculiar properties as the solvent of so-called electrolytes, and particularly its faculty of very considerably increasing the dissociation into ions of dissolved electrolytes. This phenomenon is the result of the high dielectric constant of water.

3. *Effect of Dissolved Electrolytes on the Dissociation Constant of Water.*—When electrolytes dissolve in water, they separate more or less into ions. Where the latter include H ions, they naturally increase the number of H ions in the water. Now, since $[H·] . [OH'] = K_w$ and K_w is constant at a given temperature and concentration, the increase of $[H·]$ must be accompanied by a proportionate decrease of $[OH']$, and conversely, where the dissolved electrolytes increase $[OH']$, there must be a corresponding decrease of $[H·]$. Thus acids which increase the amount of hydrogen ions in water also increase $[H·]$—*i.e.*, the C_H value, while alkaline solutions increase $[OH']$—*i.e.*, the C_{OH} value. In other words, all aqueous solutions contain hydrogen and hydroxyl ions—whether the solution is acid, neutral or alkaline. Neutral aqueous solutions are those which contain equal amounts of hydrogen and hydroxyl ions, the C_H and C_{OH} values at 22° C. being each exactly 10^{-7}. In acid solutions C_H, and in alkaline solutions C_{OH}, increases.

Hence, if we know the $[H·]$ and K_w values of any solution, we can immediately calculate $[OH']$.

4. *What is the pH Value? Its Significance in Pedology.*—The term "pH value" was introduced by the Danish chemist Sörensen.† It is simply the negative logarithm of the hydrogen-ion concentration.

In Table IV. are given the pH values and hydrogen-ion concentrations $[C_H]$ of some common acids, and in Table V. of some alkaline solutions, which are of the greatest importance from the pedological point of view, the figures having been calculated on a conductivity basis by Dr. John di Gleria.

Here I should point out that the reason why the so-called strong acids (HCl, HNO_3, H_2SO_4) are more effective than weak acids of the same concentration (acetic, citric, phosphoric acids) is that their hydrogen-ion concentration is much higher. The pH value of 0·01 normal HCl or HNO_3 is, however, about 2, while that of 1 per cent.

* MICHAELIS, L.: "Die Wasserstoffionenkonzentration," Vol. I., p. 11.
† SÖRENSEN, S. P. L.: "Enzymstudien," II. Biochem. Zeitschr., 1900, Vol. XXI., p. 131.

TABLE IV

C_H AND pH VALUES OF THE N, $N/10$, $N/100$, $N/1000$ SOLUTIONS OF SOME ACIDS BASED ON THEIR CONDUCTIVITY

	N		$N/10$		$N/100$		$N/1000$	
	C_H.	pH.	C_H.	pH.	C_H.	pH.	C_H.	pH.
HCl	7.92×10^{-1}	0·101	9.23×10^{-2}	1·034	9.7×10^{-3}	2·013	9.9×10^{-4}	3·004
HNO$_3$	7.97×10^{-1}	0·098	9.30×10^{-2}	1·031	9.8×10^{-3}	2·008	9.95×10^{-4}	3·002
H$_2$SO$_4$	5.17×10^{-1}	0·286	5.88×10^{-2}	1·231	8.1×10^{-3}	2·091	9.4×10^{-4}	3·026
Citric acid ..	1.54×10^{-2}	1·12	4.6×10^{-3}	2·337	1.21×10^{-3}	2·916	2.53×10^{-4}	3·596
Acetic acid ..	3.8×10^{-3}	2·42	1.32×10^{-3}	2·879	4.1×10^{-4}	3·387	1.18×10^{-4}	3·928

TABLE V

C_H AND pH VALUES OF THE N, $N/10$, $N/100$, $N/1000$ SOLUTIONS OF SOME ALKALIES

	N		$N/10$		$N/100$		$N/1000$	
	C_H.	pH.	C_H.	pH.	C_H.	pH.	C_H.	pH.
KOH	1.29×10^{-14}	13·89	1.12×10^{-13}	12·95	1.05×10^{-12}	11·98	1.02×10^{-11}	10·90
NaOH	1.38×10^{-14}	13·86	1.12×10^{-13}	12·95	1.07×10^{-12}	11·97	1.05×10^{-11}	10·98
NH$_4$OH	2.69×10^{-12}	11·57	7.07×10^{-12}	11·15	2.51×10^{-11}	10·60	8.51×10^{-11}	10·07

citric acid—which corresponds to 0·052 normal—is 2·13 and that of 2 per cent. citric acid (0·104 normal) is 1·95. From this it follows that the effects of 0·01 normal HNO_3 are about the same as those of 1 per cent. and 2 per cent. citric acid, which are both stronger than normal acetic acid, which corresponds to 6 per cent. acetic acid.

Alkaline solutions may also be classified as weak or strong. Here, however, the C_H value is smaller and the pH value greater in weak than in strong solutions. Particularly striking is the fact that the pH value of NH_3—even at high concentrations—is considerably less than that of the strong alkaline solutions NaOH and KOH.

In soil and rock weathering a special rôle is played by carbonic acid (*i.e.*, carbon dioxide) and humic acids, and I have therefore given the pH values of these acids in separate tables.

Table VI. contains the figures obtained by WIEGNER* for the pH value of certain concentrations of CO_2 important from the point of view of soil science.

TABLE VI

CO_2 Volume per Cent. in the Air at 18° C.	CO_2 Content of the Air Expressed in Atm. Pressure at 18° C.	CO_2 found in 1,000 C.Cm. of Water at 18° C. (in Grammes).	pH.	Notes.
0·03	0·0003	0·00054	5·72	Normal CO_2 content of the air.
0·30	0·003	0·0054	5·22	Average CO_2 content of soil air.
1·00	0·01	0·0179	4·95	High CO_2 content of soil air.
10·00	0·10	0·1787	4·45	
100·00	1·00	1·7870	3·95	Water saturated with CO_2 at 1 atmosphere pressure.

It should be noted that the dissociation constant of the humic acid found in soils lies between that of acetic acid ($1·82 \times 10^{-2}$) and that of carbonic acid ($3·0 \times 10^{-7}$).† Table VII. shows the pH values of humic acid determined by KOTZMANN.

* See WIEGNER, G.: " Anleit. z. quant. agrik. chem. Prakt. " (Berlin, 1926), p. 152.

† Compt. rend. de la Conférence extraordinaire Agropédologique à Prague (1922), pp. 225-243.

TABLE VII

1. HUMIC ACID IN N/10 SUSPENSION

(According to the Data of L. Kotzmann.)

Extracted from the soil of	" Porhany "		..	3·19 pH.
,,	,,	,,	" Csiszta " ..	..	3·40 pH.
,,	,,	,,	" Tyukod "	..	3·29 pH.

2. HUMUS OF PINE FOREST

(According to the Data of H. Hesselman.)

Humus from Schwarzwald (Black Forest),
    (Calmbach, Langenbrand) .. .. .. 3·6-3·8 pH.
Humus from Norrland .. .. 3·9-4·1 pH.
    ,,   ,,   Lappland .. .. 3·6-3·8 pH.

The figures show that the pure humic acids prepared by KOTZMANN had somewhat lower pH values than the natural humus substance given by HESSELMAN—a circumstance quite intelligible in view of the fact that under natural conditions the humic acids do not lose all the absorbed bases. It will be seen also that the pH value of N/10 humic acid is roughly the same as that of N/100 acetic acid and that humic acid is stronger than carbonic acid.

5. *The Hydrolysis of Salts dissolved in Water.*—As already stated, salts dissolved in water dissociate either partly or entirely into anions and cations—*e.g.*:

$$NaCl \rightleftharpoons Na^{\cdot} + Cl' \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(1)$$

The liberated ions, however, react with water according to the following equations:

$$Na^{\cdot} + H_2O \rightleftharpoons NaOH + H^{\cdot} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots(2)$$
$$Cl' + H_2O \rightleftharpoons HCl + OH' \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots(3)$$

Where the dissolved salt is a combination of a strong acid and a strong alkali, hydrolysis also produces a strong acid and a strong base; in very weak solutions the acid and base dissociate completely—*i.e.*, reactions (2) and (3) go completely towards the left-hand side, and the solution remains neutral, since there is no change in the concentration either of the hydrogen or hydroxyl ions. This is not so, however, when the salt of a weak acid combined with a strong base or of a strong acid combined with a weak base is dissolved in water. When, for instance, dissolved sodium acetate dissociates into ions, the sodium ions react with water as shown in equation (2), and the NaOH being a strong alkali then dissociates completely, in dilute solution, into Na· and OH'. But, since acetic acid has a weak acid anion, even in dilute solution it only slightly dissociates, with the result that the

balance between the H and the OH ions is shifted in favour of the latter.   An acetic acid salt solution consequently reacts alkaline, since its C_H value is lower and its pH value higher.   On the other hand, where the dissolved salt dissociates into strong acid anion and weak basic cation, there is an increase in the quantity of H ions, the C_H value becoming higher and the pH value lower.   This is why $AlCl_3$ and $FeCl_3$ form acid solutions in water.   Table VIII. gives the reaction numbers (pH) of some important salts.

TABLE VIII

C_H AND pH VALUES OF N, N/10, N/100, N/1,000 OF SOME SALT SOLUTIONS AND OF ZEOLITE SUSPENSIONS

(a) Salt Solutions.

	N.		N/10.		N/100.		N/1,000.	
	$C_H.$	pH.	$C_H.$	pH.	$C_H.$	pH.	$C_H.$	pH.
KCl ..	$2 \cdot 00 \times 10^{-7}$	6·7	$2 \cdot 51 \times 10^{-7}$	6·6	$1 \cdot 59 \times 10^{-7}$	6·8	$1 \cdot 59 \times 10^{-7}$	6·8
NH_4Cl ..	$3 \cdot 16 \times 10^{-5}$	4·5	$1 \cdot 00 \times 10^{-5}$	5·0	$3 \cdot 16 \times 10^{-6}$	5·5	$3 \cdot 16 \times 10^{-7}$	6·5
$CaCl_2$ ..	$6 \cdot 31 \times 10^{-8}$	7·2	$1 \cdot 59 \times 10^{-7}$	6·8	$2 \cdot 00 \times 10^{-7}$	6·7	$2 \cdot 00 \times 10^{-7}$	6·7
$AlCl_3$ ..	$2 \cdot 55 \times 10^{-5}$	4·6	$7 \cdot 94 \times 10^{-6}$	5·1	$2 \cdot 00 \times 10^{-6}$	5·7	$1 \cdot 00 \times 10^{-6}$	6·0
$(NH_2)_2SO_4$	$3 \cdot 98 \times 10^{-6}$	5·4	$7 \cdot 94 \times 10^{-7}$	6·1	$1 \cdot 59 \times 10^{-7}$	6·8	$1 \cdot 59 \times 10^{-7}$	6·8
$Al_2(SO_4)_3$..	$1 \cdot 00 \times 10^{-5}$	5·0	$3 \cdot 98 \times 10^{-6}$	5·4	$1 \cdot 59 \times 10^{-6}$	5·8	$1 \cdot 00 \times 10^{-6}$	6·0
$Na_2H_3O_2$..	$3 \cdot 16 \times 10^{-10}$	9·5	$1 \cdot 00 \times 10^{-9}$	9·0	$3 \cdot 16 \times 10^{-9}$	8·5	$3 \cdot 16 \times 10^{-8}$	7·5
Na_2CO_3 ..			$4 \cdot 47 \times 10^{-12}$	11·36				

(b) Zeolite Suspensions.

				$C_H.$	pH.
Ba zeolite	..	..	..	$2 \cdot 51 \times 10^{-9}$	8·6
Ca zeolite	..	..	..	$2 \cdot 00 \times 10^{-9}$	8·7
Na zeolite	..	..	..	$7 \cdot 94 \times 10^{-11}$	10·1

The table also shows that artificial zeolites—which to some extent resemble the saturated absorbing complexes of the soil—react alkaline although chemically they are saturated and should therefore be neutral compounds.

Let us now inquire what active substances are contained in the precipitation water which causes chemical weathering.   We have seen already that water absorbs more oxygen and even more carbon dioxide than nitrogen.   The rôle of oxygen in weathering is to oxidise oxidisable compounds.   Most of the rock-forming minerals are, indeed, fully oxidised already, so that oxygen has no effect upon them; however, we find compounds of iron and manganese which are still oxidisable, as is also dead organic matter.   The iron and manganese

in silicates are usually bivalent, at which stage of oxidation their bicarbonates are readily soluble and oxidisable by the oxygen in the precipitation water which precipitates them as hydroxides or higher oxides. In certain cases iron is found in the form of insoluble ferrous sulphide, which may be oxidised to ferrous sulphate, and under certain circumstances even free sulphuric acid is formed. Under different conditions this reaction may be reversed—viz., where there is a shortage of oxygen and the higher oxides of iron and manganese come into contact with reducing substances (e.g., humic matter). Thus, while on the one hand certain iron and manganese compounds are precipitated, on the other hand insoluble ferrous sulphide becomes mobile by oxidation. In both cases a shortage of oxygen induces the reverse process.

Opinions differ with regard to the rôle of dissolved CO_2, to which great importance was formerly attributed as a factor in chemical weathering. It has now been shown that the presence of water is in itself sufficient explanation for most of the chemical reactions ensuing and that the CO_2 found in water occurs mostly (e.g., 99·44 per cent.) as an anhydride, only a very slight proportion (e.g., 0·56 per cent.) dissolving in the form of H_2CO_3, the latter being approximately 91 per cent. dissociated into $H^{.}$ and HCO'_3. There can be no doubt, however, that carbonic-acid water reacts with both carbonates and silicates to a far greater degree than these conditions would lead us to expect. The explanation of this—that the hydrogen ions consumed are continuously replaced so long as any CO_2 remains absorbed in the water—illustrates *the importance of carbonated water as a factor in the chemical weathering of minerals*. Particularly important is the action of carbonated water in dissolving alkaline-earth carbonates ($CaCO_3$, $MgCO_3$, and dolomites) and ferrous carbonate ($FeCO_3$), which are frequently found among the decomposition products of silicates. It is highly probable, therefore, that carbonated water is an important factor in their weathering too.

It has long been known that the air contains certain quantities of ammonia, and nitrogen tri- and pentoxides. BOUSSINGAULT found that the quantity of combined nitrogen brought down on 1 hectare by the annual rainfall is altogether 2·7 kilogrammes (1·82 kilogrammes ammonia nitrogen and 0·88 kilogramme nitric acid). The figures collected at Rothamsted and Gembloux are higher (about 3·6 kilogrammes).

Of the chlorides, NaCl especially is found in air, and therefore in rain, but the bulk of it is dissolved from solid rocks. According to CLARK, the proportion of Cl in the eruptive rocks of the lithosphere averages 0·063 per cent. and in calcareous rocks 0·02 per cent. This is the origin of all the chlorides in fresh water and accumulating in sea water. Chlorides do not, however, play any important rôle in chemical weathering.

Sulphuric acid and sulphates originate either from the pyrites and

marcasite of rocks or from organic sulphur by the reduction of organic substances.

From organic sulphur certain bacteria evolve H_2S, which precipitates iron in the form of ferrous sulphide. By contact with the air H_2SO_4 is produced. Although the quantity of the sulphuric acid thus produced is usually not large, the distribution of sulphates in soils and waters proves that this process is fairly general. And since it is a strong acid, even a small quantity of sulphuric acid can play an important rôle in the process of chemical weathering. In soils carbonates are frequently followed by sulphates; indeed, in dry regions gypsum accumulation is by no means rare. Under humid conditions, however, their greater solubility renders sulphates more liable to leaching than carbonates, except where the subsoil is impermeable. In Finland, for instance, there are salty soils containing large proportions of aluminium sulphate. These are impermeable, peaty soils, so that there is an accumulation of sulphates, while as a result of hydrolysis the aluminium sulphate produces a highly acid reaction.*

Finally, the humus substances, and in particular the humic acids produced during the decomposition of dead organic matter, are also active factors in the weathering of rocks. We shall discuss their nature later. Here I will only point out that as acids they increase the hydrogen-ion concentration and thereby accelerate chemical decomposition of minerals, and as protective colloids forming emulsions they increase the stability of colloidal dispersions and thereby the mobility of the insoluble weathering products.

6. *The Effect of Hydrolysis on the Solubility of Silicates.*—From what has already been said it will be clear that the bulk of the earth's crust consists of silicates, which consequently also form the main parent mineral material of soils. According to recent theories the chemical weathering of silicates consists in the alkali and alkaline-earth cations ($K\cdot$, $Na\cdot$, $Ca\cdot\cdot$, $Mg\cdot\cdot$) going into solution with hydroxyl ions in a state of strong dissociation. In the presence of abundant CO_2, the less soluble and less dissociated $Ca(OH)_2$ and $Mg(OH)_2$ form easily soluble bicarbonates, thus considerably increasing the solution of Ca and Mg cations. Carbonic acid here plays a peculiar rôle of its own. The Fe and Mn in silicates are usually present in bivalent form, and their hydroxides, being insoluble in water, are precipitated unless the presence of abundant carbonic acid causes the formation of bicarbonates which are leached out. In contact with oxygen, however, ferric and manganic oxides and hydroxides are precipitated.

The fate of the different constituents may vary considerably according to the conditions. The most resistant are Si and Al, as their oxides and hydroxides are practically insoluble. Hence they usually accumulate in the residue from the weathering of the silicates, whereas the others are more or less leached out. Particularly resistant is

* See AARNIO, B.: "Über Salzböden (Alaunböden) des humiden Klimas in Finnland" (Intern. Mitteil. f. Bodenkunde, Vol. XII., p. 180).

Al_2O_3, for there are circumstances under which SiO_3 is almost completely leached out, only Al_2O_3 being left behind. That the weathered crust on the surface of silicates has become poorer in certain mobile constituents, and that the residue—though its composition varies—consists mostly of Al_2O_3, SiO_2 and some Fe_2O_3, is, according to RAMANN's weathering theory, attributable to the hydrolytic effects of water and to the consequent dissolutions and leachings. Recently it has also been suggested that the primary products of hydrolysis react with one another forming new chemical compounds or colloidal gel complexes, which bind, either chemically, physico-chemically or purely physically, some of the cations which would otherwise have been soluble. As the result of the weathering of the silicates there thus remains a certain insoluble complex, which becomes the seat of various absorption phenomena and may lead to the formation of new chemical compounds.

Recent researches* enable us to assert with a certain probability that the colloidal fractions of soils may contain crystalline mineral compounds (montmorillonite, halloysite, bentonite, beidellite, etc.) which to some extent resemble, without actually being, zeolites; indeed, no crystalline zeolites have been discovered in the colloidal parts of soils. Later on we shall apply the term " soil zeolites " in a collective sense to the active substance of the absorbing complex which is mineral in origin, without necessarily implying that the complex contains zeolites. This is the sense in which the term is used by STEBUTT also, his whole pedological theory being based on the formation of zeolites. His conception of the decomposition of aluminium silicates is based upon the following general principles :†

I. Original silicates:

SiO_2	Al_2O_3	MO

II. At the moment of hydrolytic decomposition:

SiO_2	Al_2O_3	MO

SiO_2 Al_2O_3 MO

* See Ross, C. S.: " The Mineralogy of Clays " (Proc. 1st Int. Cong. Soil Sc., 1928, Vol. IV., pp. 555-561); HENDRICKS, S. R., and FRY, W. H.: " The Results of X-Ray and Mineralogical Examination of Soil Colloids " (Soil Sci., Vol. XXIX., 1930, pp. 457-476); KELLEY, W. P., DORE, W. H., and BROWN, S. M.: " The Nature of the Base-Exchange Material of Bentonite, Soils and Zeolites, as revealed by Chemical Investigation and X-ray Analysis " (Soil Sci., Vol. XXI., 1931, pp. 25-56).

† See STEBUTT, A.: " Lehrbuch d. allg. Bodenkunde " (Berlin, 1930), p. 296.

III. Zeolite-formation:

$$
\begin{array}{ccc}
\boxed{\quad SiO_2 \qquad Al_2O_3 \qquad MO \quad} \\
\diagup \qquad\quad | \qquad\quad \diagdown \\
SiO_2 \qquad\quad Al_2O_3 \qquad\quad MO. \\
\diagdown \qquad\quad | \qquad\quad \diagup \\
SiO_2 \quad + \quad Al_2O_3 \quad + \quad MO + H_2O
\end{array}
$$
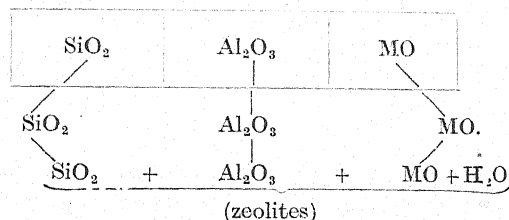
(zeolites)

Formula III. is based on the assumption that as the result of hydrolysis the original aluminium silicates first break up into their constituents, which then if conditions are favourable again partly unite in the form of zeolites. Naturally the products of hydrolysis usually unite in the form of zeolites in different stoichiometric ratios from the original silicates, so that we also find residual products, (particularly compounds containing SiO_2 and MO).

But the soil-forming factors are not always favourable to the formation of zeolites. According to STEBUTT, only the genetic circumstances producing steppe and some alkali soils cause the formation of zeolites in the neutral or slightly alkaline media prevailing during the weathering of the silicates; particularly favourable to zeolite formation is the presence of abundant $CaCO_3$ and a dry climate. Where, however, there is an entire lack or only a slight amount of $CaCO_3$ and the medium is acid, zeolites either cannot form at all or if formed are again decomposed. Where no zeolites at all are formed, the constituents broken down by hydrolysis remain separated, as shown by the following formula:

IV. Complete decomposition (destruction) of silicate molecule:

$$
\begin{array}{ccc}
\boxed{\quad SiO_2 \qquad Al_2O_3 \qquad MO \quad} \\
\diagup \qquad\quad | \qquad\quad \diagdown \\
SiO_2 \qquad\quad Al_2O_3 \qquad\quad MO \\
| \qquad\quad | \qquad\quad \diagup \\
SiO_2 + H_2O \qquad Al_2O_3 + H_2O \qquad MO + R
\end{array}
$$
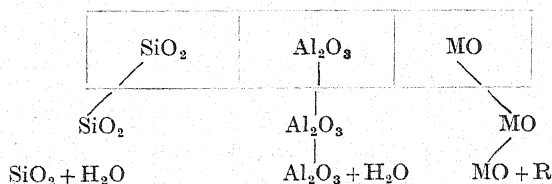
SiO_2 and Al_2O_3 combined with water form insoluble precipitates (silicic acid and aluminium hydrate gels respectively); the bases (MO), however, combined with acid ions (humic or carbonic acid) form soluble or insoluble compounds and then are either leached out or accumulate.

The second alternative referred to above usually takes place where a steppe soil comes under the influence of acid leaching processes. In this case the zeolites of the steppe soil are gradually broken up by the acid medium. The ultimate result is the same as before, but in this case the reaction has four phases as shown in formula V.:

V. Separation (degradation) of zeolites formed:

$$
\begin{array}{ccc}
\boxed{SiO_2} & \boxed{Al_2O_3} & \boxed{MO} \\
\diagup & | & \diagdown \\
SiO_2 & Al_2O_3 & MO \\
\diagdown & | & \diagup \\
SiO_2 \quad + & Al_2O_3 \quad + & MO + H_2O \\
\diagup & | & \diagdown \\
SiO_2 + H_2O & Al_2O_3 + H_2O & MO + R
\end{array}
$$
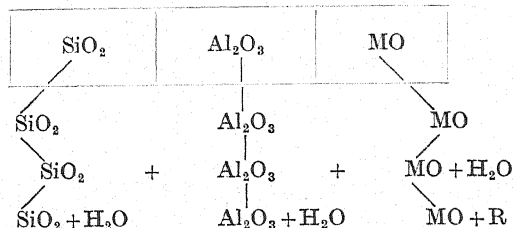
The above formulæ given by STEBUTT are particularly instructive in that they fix clearly defined types characterising the main trends of the mineral weathering processes actually taking place in soils. Naturally they must not be taken to mean that the reactions take place in one or the other direction only; but the several soil types are actually differentiated according to which of the different trends prevails and thus gives its character to the soil in question and affects its present dynamic behaviour.

There are, moreover, phenomena indicating that the chemical decomposition of silicates is a gradual process. For the silicate molecules are attacked by water or carbonated water, which first dissolves the alkali and alkaline-earth metals from the network of silicate crystals, the alkaline solution thus formed then dissolving chiefly the SiO_2, the Al_2O_3 remaining and taking up water. According to BEHREND* our present knowledge allows us to conceive the weathering of silicates taking place, not only as assumed by RAMANN and STEBUTT, but also by the dissociated OH ions *gradually* decomposing the silicate molecules, leaving *the original combination of Si and Al in the insoluble weathering residue*.

7. *Colloid-Chemical Effect of Water on the Insoluble Products of Silicate Weathering* (SiO_2, Al_2O_3, Fe_2O_3).—Colloidal dispersion does not represent any sharply defined physical condition; it is an intermediate but continuous stage between so-called coarse dispersion (larger than $100\ \mu\mu$) and molecular dispersion (less than $1\ \mu\mu$). The properties of the dispersion phase vary according to the size of the particles of the dispersed material.

It might be expected that, on coming into contact, the dispersed particles would adhere and coagulate, but that does not happen; on the contrary the colloidal dispersion, being a " sol " or colloidal solution, is stable, due to a special force keeping the particles apart. In some cases (emulsoids) a thick water envelope surrounds the ultramicrons, and in other cases (suspensions) the repulsion of electrostatic charges on the dispersed particles prevents coagulation.

As regards the electric charge on the particles WIEGNER notes that it may be due to various causes. Firstly, the frictional electricity

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* See BEHREND and BERG: " Chem. Geologie," p. 270.

arising from the movement of the particles induces a certain electric charge. Then, ions are either detached from the dispersed particles or are taken up from the dispersion medium by the dispersed particles; in both cases the result is that the dispersion phase becomes electrically charged. For instance, where negative ions are detached by the dispersion phase (dispersed particles) or where positive ions are taken up out of the dispersion medium by the dispersed particles (*e.g.*, from a water solution), the dispersed particles or ultramicrons become positively charged. The electrical charge ensures the stability of *suspensoids*, as is proved by the phenomenon of *cataphoresis* or *electroosmosis*. When we introduce into a dispersion system a positive and a negative pole, the normally negative (*e.g.*, clay and humus)
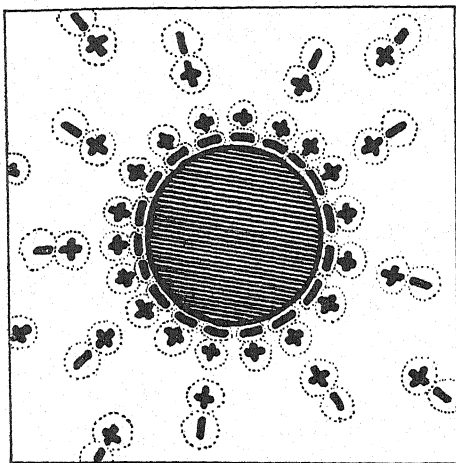
[FIG. 1.—AN ULTRAMICRON IN DISPERSING MEDIUM CONTAINING ELECTROLYTES.

particles migrate to the positive pole, while the positive dispersion medium migrates to the negative pole. The migration of the dispersion phase is called *cataphoresis*, and that of the dispersion medium *electroendosmosis*. The electric charge on the suspended particles is usually very high, increasing with the size of the particles. According to WIEGNER*, every suspended—*i.e.*, dispersed—particle is surrounded by a double ion layer. The inner ion shell, which adheres to the particle's surface as the skin does to the hand, is the layer which determines the electric charge on the particle and the stability of the dispersion. The outer ion shell, composed of ions with opposite charges to the inner shell, is a thick layer in dynamic equilibrium both with the electric forces of the inner shell and with the ions of the dispersion medium. This is illustrated by Fig. 1. WIEGNER compares

* See WIEGNER, G.: "Dispersität und Basenaustausch" (Actes de la IVème Conf. Int. de Pédologie, Rome, 1924, Vol. II., p. 395).

the outer shell to a glove, which may be taken off without the skin adhering to the hand coming off with it. This is what happens in *cataphoresis*, when the negative ultramicrons migrate to the positive pole and the positive cations to the negative pole.

The stability of a suspension depends upon the electric potential of the suspended particles, this being expressed by WIEGNER in the following formula:

$$V = \frac{n \, \varepsilon \, \delta}{D \, r^2}$$

where V = electrical potential; n = number of the ions in the outer shell; ε = quantity of elementary energy; δ = distance between outer and inner shell; D = dielectric constant; r = radius of the particle. Thus the electric potential varies directly with the charge on the ions and the thickness of the outer ionic layer, and inversely with the dielectric constant and the radius of the particle. The distance δ decreases in proportion to the decrease in the hydration of the outer ions and to the increase in their electric charge. Experience shows that in general the potential of colloidal particles ranges from 16 to 58 millivolts and that usually when the potential falls below a critical point the dispersion coagulates. The critical point varies with the thickness of the outer ion shell and with the degree of hydration of the ions. For instance, the potential of lithium clay is higher—and its sol more stable—than that of caesium clay; for the degree of hydration of lithium ions is the highest and that of caesium the lowest of the alkali metal cations. Hydrogen is the least hydrated of all. Consequently, the stability of the clays saturated with various cations increases from left to right in the following series: H-clay, Cs-clay, K-clay, Na-clay, Li-clay. The bivalent alkaline-earth metals form a similar lyophobe series, but, on account of their double electric charge, their clays are less stable than those of the monovalent cations. They can, however, be grouped according to the degree of their stability in the following order:

Ba-clay, Sr-clay, Ca-clay, Mg-clay.

This is the reason why soils saturated with sodium become fluid, while calcium soils coagulate.

Owing to their minuteness colloidal particles cannot be retained except by very fine filters. Sols of very fine dispersion may, indeed, be as mobile in soils as true solutions.

We shall now consider in detail the three principal colloidal materials produced by the weathering of silicates—viz., silicic acid and hydrated aluminium and ferric oxides.

(a) *Silicic Acid*.—As we have seen, silicic acid is a decomposition product of silicates; in all probability at the moment of decomposition and for a certain time afterwards it is present in true solution and in various forms. It is true that SiO precipitates very rapidly out of

colloidal dispersions, forming silicic acid gels of varying density, which have been closely investigated by VAN BEMMELEN,* but data exist indicating that silicic acid may also be present in molecular dispersion—*i.e.*, in true solution.

The final conclusion reached by BEHREND† is as follows: In natural weathering solutions silicic acid is usually found as alkali silicate which, however, gradually decomposes into molecular solutions of alkalies and silicic acid, the latter then forming a colloidal dispersion. Consequently, *during weathering silicic acid first appears as a molecular solution, remaining as such for a considerable time under favourable conditions, so that it may take part in chemical reactions.*

It must be borne in mind, however, that the dissociation constant of silicic acid is not yet known. Most scientists are of the opinion that at normal temperature and in a weak solution silicic acid is only slightly dissociated. Its salts all decompose and produce an alkaline reaction. From what has been said, however, it is evident that this phenomenon can be attributed primarily to the fact that, while the colloidal silicic acid produced by the hydrolysis of silicates does not take part in any chemical reaction, the hydroxides of the alkalies and alkaline-earths chemically combined with the silicic acid form a true solution in molecular dispersion and in a highly ionised condition, increasing thereby the OH' concentration of the water. For this reason NIGGLI and JOHNSTON‡ refuse to endorse the general view that silicic acid is a weak acid.

(b) *Aluminium Oxide.*—The general opinion is that Al_2O_3 is the least mobile decomposition product of the weathering of silicates. Hence the loss caused during silicate weathering is usually reckoned on the basis of the ratio of the Al_2O_3 to SiO_2. Under certain circumstances, however, the Al_2O_3 may also migrate—*e.g.*, in soils in which protective colloids such as humus sols prevent the precipitation of aluminium oxide. Of peculiar interest to the pedologist is the precipitation of aluminium oxides due to the effect of silicic acid sols. The latter being usually negatively charged, while Al_2O_3 suspensions are positively charged, the two oppositely charged suspensions precipitate one another more or less completely.

On this point I obtained interesting results during my researches on artificial zeolites. For my experiments I used solutions of sodium silicate and sodium aluminate. These solutions I prepared by dissolving in approximately normal NaOH as much SiO_2 and Al_2O_3 respectively as was possible at normal room temperature. Though mixed in varying proportions these solutions always yielded a white precipitate, while the solution remaining was far more alkaline than the original one. I shall not discuss here the question whether the precipitates formed are true chemical compounds or merely mutual

* See VAN BEMMELEN: "Die Absorption" (Steinkopff's Verlag, Dresden, 1910).
† See BEHREND and BERG: "Chem. Geologie," p. 302.
‡ See NIGGLI, P., and JOHNSTON, I.: N. Jahrb. f. Min., 1914, Vol. XXXVII., p. 529.

precipitations of SiO_2 and Al_2O_3 gels; the fact remains that by changing the initial ratios of SiO_2 and Al_2O_3 both the composition and quantity of the precipitate changed (see Table IX.).

TABLE IX

Initial Ratio of Al_2O_3 : SiO_2.	Percentage of Precipitation calculated to the Original Content of :		
	SiO_2.	Al_2O_3.	$SiO_2 + Al_2O_3$.
1 : 1	100	37·39	60·6
1 : 2	100	75·06	90·8
1 : 3	93	95·2	93·8
1 : 4	79	92·6	82·4
1 : 5	70·8	97·7	77·6
1 : 10	76·4	100·0	54·4
1 : 20	32·1	100·0	37·7

The table shows that in a highly alkaline medium, and with an initial ratio of approximately 1 part Al_2O_3 to 3 parts SiO_2 about 95 per cent. of the dissolved Al_2O_3 and about 93 per cent. of the SiO_2 are precipitated. With wider ratios the precipitation of Al_2O_3 increases and that of SiO_2 decreases. In felspars the ratio of Al_2O_3 to SiO_2 ranges from 1: 2 (anorthite) to 1: 6 (albite, adular), approximating the latter ratio in the alkali felspars. The quantity of Al_2O_3 precipitated in the alkaline solutions produced during weathering exceeds that of SiO_2. During the further course of my research work it was also shown that the dissolution of SiO_2 may be considerably increased by increasing the relative quantity of Na_2O.* The relevant data are given in Table X.

TABLE X

Experiment No.	Initial Molecular Ratio of :			Parts per 100 Na_2O in the Original Solution of :			Molecular Ratio in the Final Precipitate:		
	SiO_2 : Al_2O_3 : Na_2O			SiO_2	Al_2O_3	$SiO_2 + Al_2O_3$	SiO_2 : Al_2O_3 : RO		
6	10 : 1 : 4·58			218·5	21·85	240·30	4·57 : 1 : 0·98		
8	10 : 1 : 11·68			85·59	8·56	94·1	3·47 : 1 : 1·02		
9	10 : 1 : 10·62			94·12	9·41	103·5	3·44 : 1 : 1·22		
10	10 : 1 : 21·25			47·06	4·70	51·8	3·03 : 1 : 1·00		

* See SIGMOND, A. A. J. VON: "Über die Charakterisierung des Bodens auf Grund des salzsauren Bodenauszuges, etc." (Int. Mitt. f. Bodenkunde, Vol. IV., 1915, pp. 352-6).

The above data prove clearly that an increase in the molecular proportion of Na_2O is accompanied by a considerable decrease in the proportion of SiO_2 found in the precipitate.

We shall return to these experiments, because we must fully understand the behaviour of the precipitates thus formed. In the present connection I merely wish to show that *in an alkaline medium the Al_2O_3 is usually precipitated together with a part of the silicic acid and with some of the bases, while the rest of the silicic acid and bases remains in solution and may be leached out. This occurs during the weathering of natural silicates in pure water. In an acid medium, however, different conditions prevail; to this point we shall return later.*

Aluminium does not form stable compounds with weak acids nor with carbonic acid except under special circumstances. In this respect it differs essentially from iron and is consequently far less mobile. Aluminium is mobile only when some strong mineral acid (*e.g.*, sulphuric acid) is present—*i.e.*, where aluminium sulphate is formed and may therefore be leached out. So far no one has succeeded in preparing a true molecular solution of Al_2O_3; but the structure of the hydroxides of aluminium are well known from the X-ray, spectroscopic and chemical experiments of HABER,[*] WILLSTÄTTER,[†] KRAUT[‡] and BÖHM.[§] Thus it is known that hydrargillite corresponds to the orthohydroxide $Al(OH)_3$, and bauxite and diaspore to the meta-hydroxide $AlO(OH)$. There is a series of polyhydroxides between these two hydroxides. The adsorption capacity of $Al(OH)_3$ is high, that of $AlO(OH)$ is low. In general $Al(OH)_3$ when in a fresh state is very reactive; but gradually it loses some of its reactivity (hysteresis), becoming less soluble in both acids and alkalies.

(c) *Iron.*—Iron in silicates is usually bivalent, though during weathering it generally becomes trivalent and stabilises as $Fe(OH)_3$. It possesses colloidal properties similar to $Al(OH)_3$, though it is by no means so stable as the latter. This is due partly to its being reducible and to the fact that the ferrous compounds are easily soluble, while ferric compounds hydrolyse easily—like the corresponding compounds of Al—and form $Fe(OH)_3$. Bivalent iron is a very mobile constituent in soils, combining with humus sols either to form soluble humates or colloidal sols; but where circumstances are favourable to its oxidation, it precipitates and forms concretions. According to the results shown by BÖHM's X-ray spectroscopic experiments,[||] goethite corresponds to the formula $FeO(OH)$. Limonite and other similar brown ferric hydrates have proved to be fine crystalline goethite. Freshly precipitated ferric hydroxide—$Fe(OH)_3$—has on the other

* See HABER, F.: Ber. D. Chem. Ges., 1922, Vol. LV., p. 1717.
† See WILLSTÄTTER: *Ibid.* (1925), Vol. LVIII., pp. 2448-58 and 2458-62.
‡ See KRAUT, H.: Zentralblatt f. Min., 1926, Vol. CXLIX., pp. 64-80.
§ See BÖHM, J.: Zeitschr. anorg. Chem., 1925, Vol. CXLIX., pp. 203-06.
|| See BÖHM, J.: Zeitschr. anorg. Chem., 1925, Vol. CXLIX., pp. 210-16.

hand proved to be an amorphous material which after dehydration forms Fe_2O_3, from which we again get goethite by heating with KOH. Since $Fe_2(OH)_3$ sols are positively, while the surface of most minerals is negatively, charged, $Fe(OH)_3$ dispersions are adsorbed on the surface of most minerals, while under similar circumstances SiO_2 or clay soils, being negatively charged, are not adsorbed. Quite recently REIFENBERG has shown that silicic acid sols may render mobile oxides and hydroxides of iron, combining with them to form peculiar adsorption compounds, the striking colours of which are responsible for the characteristic colours of certain soils (red earth, brown earth, etc.).* In combination with ferrous oxide silicic acid forms green sols which turn yellow when oxidised, and reddish-brown sols with colloidal ferric hydroxide.

(d) *Chemical Weathering Products.*—The products of chemical weathering may be grouped in various ways. Taking first their physical behaviour, we find that while some dissolve in water and are therefore very mobile and easily leachable, others are completely or almost completely insoluble, thus accumulating as a weathering residue. The dissolved materials may be either molecularly dissolved compounds or very fine colloidal dispersions (sols). The insoluble part may be either crystalline or amorphous, the latter being either loose gels or solids. As a consequence of these differences in physical properties, the end product of weathering varies considerably according to the circumstances.

Taking their chemical behaviour, we find that here too the decomposition products resulting from the weathering process are very various. Some are well-defined chemical compounds, mostly salts, which ionise more or less in water. Although these products are chemically speaking the most active weathering materials, nevertheless, being easily soluble, they are generally leached out and cannot be recovered in the weathering residue. In the residue we may also find some well-defined salts (*e.g.*, $CaCO_3$, $CaSO_4$, $Ca_3(PO_4)_2$, etc.), but it is mainly a mixture of unknown chemical compounds.

However, in a review of the products of chemical weathering it is not enough to discuss only the soluble constituents. For the minerals can be decomposed in various ways and degrees. Sometimes a mineral is entirely dissolved on the surface, leaving gaps or holes unfilled or filled only by newly formed insoluble products precipitated from solution. It may also happen, however, that the most exposed and most loosely combined constituents are separated from the crystalline frame by dissolution or exchange. In the case of alkaline felspars, for instance, only the alkalies are exchanged by hydrogen and only a part of the silicic acid is leached, while the most resistant nucleus remains behind, forming kaolin in place of the original felspar. Again, when the iron is extracted from black mica, the original atomic structure of the

* See REIFENBERG, A.: "Die Entstehung der Mediterran-Roterden (Terra Rossa)," Dresden and Leipzig, 1929, pp. 61-3.

mineral is left intact (called by RINNÉ " Baueritisierung "). This is the residual mineral structure described by HARRASSOWITZ.* Sometimes this residue is very loose, and the crystalline atomic structure disintegrates completely, leaving behind very loose material. In the case of olivine, for instance, all the Mg and Fe is removed, leaving behind pure silicic acid gels. According to HARRASSOWITZ, the decomposition of felspars is not continuous, but takes place at intervals and abruptly. The first phase is the dissolution of the alkalies and alkaline-earths, followed by the removal of the more loosely combined silicic acid. This leads again to the formation of various transitional weathering residues, the principal representatives of which are the so-called allophanes—kaolins and laterites.

BEHREND distinguishes three types of silicate weathering—viz., clay, kaolin and laterite formation. The formation of kaolin he describes as being merely a special variety of clay formation, so that strictly speaking there are only two main types of silicate weathering —viz., laterite and clay formation.

During the process of laterite formation, BEHREND found that the residue consisted mainly of Al_2O_3, Fe_2O_3 and H_2O; in the case of clay formation chiefly CaO and Na_2O were leached out, the loss of SiO_2 being only slight, while the other constituents apparently increased.

HARRASSOWITZ also to some extent couples clay and kaolin formation, but, in order to understand his theory, we must first consider certain mineralogical and petrographical terms, the definition of which, as given in scientific literature, is very vague and at times even contradictory.

HARRASSOWITZ applies the term *kaolin* to that crystalline mineral which can be decomposed by concentrated sulphuric acid but not by hydrochloric acid, and the composition of which is $Al_2O_3.2SiO_2.2H_2O$. He uses the term *kaolinite* for rock composed chiefly of kaolin.

He uses the term *allophane* for the aluminium hydro-silicates of colloidal dispersion unknown in the form of microscopic crystals which can be decomposed by strong hydrochloric acid, though their chemical composition varies. The term *allophanite* is applied by him to rock which consists principally of *allophane*.

He calls kaolinite and allophanite by the common collective term *siallites*. These are alumino-hydro-silicates.

The term *bauxite* is applied to rock which consists principally of the monohydrate of aluminium oxide, $Al_2O_3.H_2O$ or $AlO(OH)$.

The term *laterite* is applied to rock which consists chiefly of the almost crystalline trihydrate of aluminium oxide, $Al_2O_3.3H_2O$, or $Al(OH)_3$.

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* HARRASSOWITZ, H.: " Laterit, Material und Versuch 6. erdgeschichtlicher Auswertung." (Fortschritte d. Geol. u. Paleontologie, Vol. IV., 1926, pp. 266-71.)

Bauxite and laterite are *allites*—rocks consisting chiefly of hydrates of aluminium oxide.

This grouping is clear and inclusive; for that reason I have thought it expedient to refer to it in detail, although scientists do not always employ the terms in HARRASSOWITZ's sense. But all scientists agree that there is a definite difference between the amorphous alumino-hydro-silicates decomposed by strong HCl (*i.e.*, VAN BEMMELEN's A-complex) and kaolin; for the latter is of invariable composition and cannot be decomposed by hydrochloric acid, only by strong H_2SO_4 (VAN BEMMELEN's B-complex).

From what has been said, it will be seen that during the weathering of the silicates there may be formed both zeolitic and other compounds besides Al_2O_3 and SiO_2 gel mixtures—all these being characterised as easily attacked by hydrochloric acid and as having more or less base-exchange capacity. Kaolin, on the other hand, cannot be decomposed —or only very slightly—by hydrochloric acid; and it does not possess any cation absorption until after it has been boiled or fused with alkali. It is evident, therefore, that in the latter case the connection between SiO_2 and Al_2O_3 is closer than in the former and is of a different kind.

An interesting fact established by HARRASSOWITZ,* which would appear to confirm the above hypothesis, is that whereas in the case of orthoclase kaolin may really be formed, the products resulting from calcium and sodium felspars are allophanoids. It would seem that in orthoclase the aluminium combines better with a part of the SiO_2 (in the ratio $Al_2O_3 : 2SiO_2$) than with the rest of the silicic acid or than in calcium felspars, in which, as is well known, the ratio of silicic acid to aluminium oxide is different. Should this hypothesis be confirmed by later researches, the formation of kaolin or allophane (zeolite) is effected independently not only of external factors and circumstances, but also of the original mineral material. In both cases, however, the process has really three phases:

1. Removal—in various degrees—of the bases (CaO, K_2O, Na_2O) of the original silicate.

2. Absorption of various quantities of chemically bound water.

3. Some leaching of silicic acid.

Where the last phase is complete, the formation of allites—*i.e.*, either laterisation or bauxite-formation—takes place. If this is so, the formation of allophane or kaolin is an intermediate or initial stage of laterisation.

To sum up, the final residues of silicate weathering may be divided into three types:

1. Clay formation, resulting in a compound of varying proportions of zeolitic and kaolinitic materials, and in temperate zones the natural weathering product of silicates.

* See HARRASSOWITZ, H.: "Laterit stb." (Fortschr. d. Geologie u. Paleont., Vol. IV., p. 260).

2. Kaolin formation, resulting in a crystalline or earthy product composed of pure $Al_2O_3.2SiO_2.2H_2O$, which originates from the complete removal of the bases and of a considerable part of the SiO_2.

3. Laterite formation, resulting from the almost complete removal of silicic acid, and apparently taking place only in tropical or subtropical climates.

CHAPTER II

CLIMATIC SOIL-FORMING FACTORS

THE word " climate " is of Greek origin referring to the angle of incidence of the rays of the sun, and, indeed, at any given point on the earth's surface the climatic factors vary according to this angle of incidence and its periodical changes. KÖPPEN* defines climate as the average weather conditions and their normal course at any given geographical point. The weather is variable, but—apart from certain deviations—the climate is constant.

From the variable weather conditions and meteorological data we can obtain a comprehensive synopsis of all the meteorological phenomena which may affect living or lifeless objects existing on the earth. This agrees with another definition, according to which climate is the totality of those atmospheric factors which make the various regions of our globe more or less suitable for supporting the life of men, animals and plants, and through which it exerts a very considerable influence on soil formation.

The influence of climate on soil formation and on the soil itself is both direct and indirect. In the previous chapter we saw the many-sided and far-reaching effect of atmospheric factors on the various rocks and minerals which constitute the raw material of the soil. The intensity of these various atmospheric influences depends upon local climatic conditions. Where the climate is more humid, for instance, rock weathering and soil leaching are more active than in drier regions. Similarly, where the climate is warmer, the reactions are more intense, unless an increase of aridity counterbalances the effect of higher temperature. As we already know, fluctuations of temperature themselves lead to an energetic physical weathering of rocks. Where the atmospheric precipitation is in excess of the quantity absorbed by or evaporated from the earth, the water runs off the surface and produces all the dynamic effects of moving water —erosion, deposition, gullies, inundations, accumulation of mud, etc. And where the evaporation energy is high enough to enable even the water that originally percolated into the soil to rise in the capillaries and evaporate on the surface, soluble salts, not only from the upper

* See KÖPPEN, W.: " Die Klimate der Erde " (Berlin and Leipzig, 1923).

but also from the lower horizons, rise to the surface and accumulate there and indeed frequently effloresce.

These examples illustrate the direct effect of climate upon soil formation. But a part is taken in the formation—and indeed in the life—of the soil by the biosphere also; for the whole living world is either directly or indirectly included among the factors of soil formation. This is another reason why it is so important from the point of view of soil formation to know how far the climate in any given place influences the life of plants, micro-organisms, animals and human beings. From a general climatological point of view the climate of the oceans may be just as important as that of the continents inhabited by men; yet from a pedological point of view oceanic climates are of interest only so far as they exercise an important influence upon continental climates and thus affect the development of soils.

Climatology is fully described in the very extensive literature* on the subject, to which the reader is referred.

1. Types of Climate : Their Grouping and Relative Frequency.

(1) *Ocean Climate.*—Cool summer, mild winter, only slight variations of temperature as between seasons, and day and night. The air is humid, the winter is rainy, and the maximum and minimum temperatures are always considerably (at times even two months) later than the solstices. Spring is warmer than autumn. The number of cloudy days is considerable; winds are strong, the air is pure and dust-free and contains salt.

(2) *Continental Climate.*—In contrast to the previous type, here the extremes are better developed in respect both of seasons and of daily fluctuations; there are periodically thunderstorms or cloudbursts. The winter is damp. Winds are not so strong or are entirely unknown.

(3) *Desert Climate.*—An extreme form of the continental climate characterised in particular by the dryness of the air and by lack of

* HANN, J.: "Handbuch der Klimatologie," 3rd Ed. (Stuttgart, 1808-11); KÖPPEN, W.: "Klimakunde" (Sammlung Goschen, Leipzig, 1906); KÖPPEN, W.: "Die Klimate der Erde" (Berlin and Leipzig, 1923); DEFAUT, A., and OBST, E.: "Lufthülle und Klima" (Encykll. d. Erdkunde, Vienna, 1923); MARTONNE, E.: "Traité de Géographie Physique" (Paris, 1919); HETTNER, A.: "Die Klimate der Erde" (Geogr. Zeit., 1911); PENCK, A.: "Versuch einer Klimaklassifikation auf physiogeographischer Grundlage" (Sitzungsbericht d. preussischen Akad. Wiss., Physisch-math. Klasse, 1910, pp. 236-46); KNOCH, K.: "Die Klimafaktoren und Übersicht der Klimazonen der Erde" (Blanck's Handb. d. Bodenlehre, Vol. II., 1929, pp. 1-53); SCHUBERT, J.: "Das Klima der Bodenoberfläche und der unteren Luftschicht in Mitteleuropa" (*ibid.*, pp. 54-91); WASMUND, E. "Klimaschwankungen in jüngerer geologischer Zeit" (*ibid.*, pp. 92-128); SCHELLENBERG, G.: "Die Pollenenalyse, ein Hilfsmittel zum Nachweis der Klimaverhältnisse der jüngsten Vorzeit und des Alters der Humusablagerung" (*ibid.*, pp. 139-47).

clouds. Cloudbursts are rare; where they occur they may cause great inundations. As a consequence of the strong irradiation and eradiation the soil shows considerable fluctuations in temperature which are taken over by the surrounding atmosphere. The interchange with the upper strata of air causes strong currents which stir up the desert dust, which settles again in the evening. To similar causes may be attributed the various kinds of tornadoes often in evidence in deserts and also the warm winds (*e.g.*, the sirocco) that pass from deserts to adjoining regions.

(4) *Littoral Climate.*—The currents of air originating from the sea or the continent respectively fluctuate very rapidly, though the amplitude is not large. In general there is abundance of precipitation and clouds; only the western shores of the trade-wind regions are dry. In higher latitudes it is just the reverse, for the prevailing west winds make the western shores damper and warmer, the eastern shores being dry and cold.

(5) *Monsoon Climate.*—In summer an ocean and in winter a continental climate. The greatest heat occurs previously to the season of the æstival monsoons. In autumn, at the end of the monsoon period, the temperature is not so high, though it is far more unbearable owing to the air after the summer rains being close and oppressive.

(6) *Forest Climate.*—The currents of air are checked by the close forests, which reduce the daily extremes of temperature, though in the clearings those extremes may be felt. In its upper horizon the soil retains the moisture, which may be very considerable in the tropics. The effect exercised on the volume of the precipitation by forests is slight and uncertain; but the mists precipitate on the branches and twigs, increasing the humidity of the forest air and soil. Forest soils in general are humid.

(7) *Mountain and Alpine Climates.*—The decisive influence is the altitude. At a height of about 3,000 metres the atmospheric pressure decreases to about 500 mm. (to such an extent as to make the conditions unsuitable for human existence). At lower altitudes the mountain climate is healthy and, indeed, acts as a restorative, owing to the intensity of eradiation, particularly on slopes facing south. The refraction of heat on snow-covered mountains may be very considerable. In any case we must distinguish between the climate of slopes, valleys and plateaus. On slopes the wind is usually strong, while in closed valleys the air is quite still; plateaus protected by high mountain walls often assume an absolutely continental character. Mountains in general often form barriers separating climates.

The types of climate enumerated above may, however, vary with latitude and geographical position. Consequently, in order to characterise, and show the geographical distribution of, the climates ruling in different regions, we need permanent characteristics which on the one hand illustrate the joint effect of all the climatic factors, and on the other hand express also the fluctuations of single

factors. DE CANDOLLE introduced a classification of climatic zones based upon their natural vegetation,* since it is on the natural vegetation that climate primarily exercises a permanent influence. The same starting-point was adopted by GRIESEBACH,† DRUDE‡ and KÖPPEN;§ but WOJEKOW‖ and PENCK¶ take the hydrological conditions as determining climate.

The latest classifications of climates are based upon meteorological-statistical data (DE MARTONNE,** HETTNER,†† KÖPPEN‡‡ and others). The most perfect of these is KÖPPEN's,§§ and we shall now consider the terrestrial zones to which he has given the name of " *geographical climatic zones.*"

Instead of the three types of astronomical zones previously distinguished (*i.e.,* 1 *tropical* but 2 *temperate* and 2 *arctic* zones), KÖPPEN distinguishes *five types*:

Zone A.—Tropical humid zone, where there is no winter.

Zone B.—The arid zones lying north and south of Zone A.

Zone C.—The two adjoining warm temperate zones in which there is no snow cover.

Zone D.—The boreal zone, found only in the northern hemisphere, which possesses decided summer and winter seasons; this is the forest zone.

Zone E.—The snow-covered zones of the arctic regions where trees cannot live.

KÖPPEN uses capital letters to designate the zones. A further classification being necessary, he expresses the subdivisions by a second letter, used with the following meanings:

S=steppe climate ⎫ in Zone B.
W=desert climate ⎭

T=tundra climate with mild summer ⎫ in Zone E.
F=eternal frost without a warm season ⎭

s=main dry season is summer ⎫ in Zones A, C and D.
w=main dry season is winter ⎬
f=humid the whole year round. ⎭

* See DE CANDOLLE, A.: " Géographie botanique raisonée " (Arch. Sci. Bibl. Univ. Genève, 1874).

† GRIESEBACH, A.: " Die Vegetation der Erde nach ihrer klimatischen Anordnung " (Leipzig, 1872).

‡ DRUDE, O.: " Die Ökologie der Pflanzen " (Braunschweig, 1913).

§ KÖPPEN, W.: " Versuch einer Klassifikation der Klimate " (Geogr. Zeit., 1900, pp. 593 and 657).

‖ WOJEKOW, A.: " Die Klimate des Erdballes " (Jena, 1887).

¶ PENCK, A.: " Versuch einer Klimaklassifikation auf physiographischer Grundlage " (Sitzsber. preuss. Akad. Wiss., Phys.-math. Kl., 1910, p. 236).

** See DE MARTONNE, E.: " Traité de Géographie " (Paris, 1909, p. 205).

†† See HETTNER, A.: " Die Klimate der Erde " (Geogr. Zeit., 1911).

‡‡ See KÖPPEN, W.: " Klassifikation der Klimate nach Temperatur, Niederschlag und Jahreslauf " (Peterm. Mitt., 1918, pp. 193 and 243).

§§ See KÖPPEN, W.: " Die Klimate der Erde " (Berlin and Leipzig, 1923, p. 98).

TABLE XI

CLIMATIC ZONES AND TYPES OF KÖPPEN

Climatic Zones.	Types.	Characteristics.
Humid tropical (A) ..	1. Af	Tropical forests, continuously rainy climate.
	2. Aw	Savannahs, alternating rainy seasons with dry periods.
Arid tropical (B) ..	3. BS	Steppes.
	4. BW	Dry deserts.
Temperately warm (C) ..	5. Cw	Warm climate with dry winter.
	6. Cs	,, ,, ,, ,, summer.
	7. Cf	Moderately humid the whole year round.
Boreal, with ordinary cold winter, common forest zone (D)	8. Dw	Cold and dry winter.
	9. Df	Cold and humid winter.
Arctic, continuous snow	10. ET	Tundra, with a short summer period.
	11. EF	Eternal frost, without any warm season, lifeless.

The first four types of climate (Af—BW) figuring in Table XI. show four grades of aridity in the torrid zones characterised by tropical forests, savannahs, steppes and deserts respectively. In the warm temperate zone types, Cw and Cs are characterised by evergreen shrubs, while Cf is characterised by common forests. The latter are also the characteristic features of type Df; indeed, even in Dw the effect of drought is not felt in winter (except in the more southerly regions), so that the prevalent form of vegetation here too is forest, the cold being not so intense or so lasting as in Zone E. In Zone E we have also the tundra zone which, though treeless, has a peculiar vegetation of its own; while the zone of eternal frost is entirely lacking in vegetation.

WAGNER has calculated* the area (in millions of sq. kilometres) of the eleven types of climate differentiated by KÖPPEN. The results of his work are summarised in Table XII.

For the purpose of further differentiation KÖPPEN has introduced what are known as "Köppen's climate formulæ," with which, however, I do not propose to deal in detail.

2. Description and Pedological Connections of the Climatic Zones.

(a) *The Tropical Rainy Climate* (A).—The general characteristics of this climate, which covers nearly 40 per cent. (36·1 per cent.) of the earth's surface, are uninterrupted, equable warmth, the average

* See WAGNER, H.: Peterm. Mittl., 1921, p. 216.

TABLE XII

	Land.	Sea.	Total.	Percentage.
1. Af	14·0	103·3	117·3	23·0
2. Aw	15·7	51·1	66·8	13·1
3. BS	21·2	12·9	34·1	6·7
4. BW	17·9	2·2	20·1	3·9
5. Cw	11·3	1·4	12·7	2·5
6. Cs	2·5	10·7	13·2	2·6
7. Cf	9·3	103·2	112·5	22·1
8. Df	24·5	5·3	29·8	5·8
9. Dw	7·2	0·7	7·9	1·3
10. ET	10·3	57·8	68·1	13·4
11. EF	15·0	12·5	27·5	5·4
Total ..	148·9	361·1	510·0	100·0

temperature of the coldest month being more than 18° C., and for the whole year from 24° to 30° C., though the annual amplitude is barely 5° C. and indeed near the Equator even less ($<3°$ C.). As a consequence the seasons are divided according to the quantity of precipitation, not according to temperature.

In this zone the most important rôle is played by the distribution of precipitation, which governs the relation between climate and vegetation and is the main influence affecting the formation of the soil. The differences in temperature which differentiate the three main types (*Af*, *Am*, *Aw*) of this zone arise from differences in the distribution of the precipitation.

Af, rainy climate of tropical primeval forest, which does not possess any pronounced dry season. Its vegetation consists of tall evergreen trees covered with all kinds of creepers. The useful plants found here are sago, olives, Deleb palms, raphias, ravensara, pepper, cocoa, peanuts, bread-fruit trees, etc. The whole year round the exterior of the forests never changes materially, except as the several species bud, blossom and bear fruit. The soil is enriched with such large quantities of dead vegetable matter that despite the high rate of decomposition and leaching *the soils are all rich in humus*.

Am, the forest climate of monsoon regions, lies between *Af* and the savannah climate. At a certain period of the year the hilly littoral regions are swept by monsoons which bring such enormous quantities of water that, even during dry periods, the soil does not dry out sufficiently to cause the forest vegetation to suffer. The amplitude is larger than in *Af* and may rise as high as 8° C. The annual rainfall varies from 1,000 to 2,500 mm., according to the length of the dry season.

Aw, the savannah climate, occurs in tropical rainy zones possessing a decidedly dry season, the annual rainfall being lower than in *Am,* and the temperature amplitude rising to even 12° C. The savannahs are open prairie lands growing grasses, bushes and single trees, such as the sandal tree (*Santalum album*), which is a typical product of savannahs. Primeval forests are not found here; but in the less dry parts deciduous trees form whole forests. Economic plants include coffee, sugar-cane, ginger, tropical buckwheat, bananas, sweet potatoes, rice and cotton. It is in this climate that we find the best developed laterites, the dry seasons followed by rainy periods being apparently necessary for their development. For if only high temperature and rainfall were required, we ought to find even more laterites in the *Af* climate.

(*b*) *Dry Warm Zone* (*B*).—The torrid and humid equatorial zone is surrounded on the north and the south by the warm and arid zone. The savannah areas form a kind of bridge connecting the humid and the arid zones.

In the dry warm zone the aridity may be either so intense that it destroys all vegetable life, or also it may permit the existence of certain plants (*xerophytes*) that can tolerate drought. There are dry regions in which there is not a single drop of rain for years in succession; but if the soil ultimately obtains moisture either by rainfall or by artificial irrigation, it immediately becomes green and capable of yielding luxuriant crops. The natural vegetation also changes according to the degree of dryness. In general, however, the most abundant are xerophytic plants, grasses, thorny bushes or plants covered with resin and often possessing fleshy leaves and other similar organs adapted to minimise evaporation. The other factor of importance determining the quality and density of the natural vegetation is the soil. We find in clayey soil, for instance, different plants from those found in sand or in the rocky débris of deserts; the thin and short-lived pastures of the light loess soils are different from the luxuriant grassy steppes of tshernosems, which again differ completely from the poor—partly halophytic—vegetation of saline soils. In the latter soils the vegetation has to possess a high capacity to resist not only drought but also the considerable salt concentration. I cannot enter into a detailed description of the dry warm climate, but should mention that here, as on the open sea, the winds meet with little resistance. And as the soil heats up rapidly every day (where the temperature of the air exceeds 40°, it is quite common to find a soil temperature of 60°), causing a rapid, horizontal exchange of air, this climate is the natural home of whirlwinds, air-spouts, tornadoes, etc. All this may induce on the one hand an increase of aridity due to an increase of the evaporation, and on the other hand may involve the mixing or transport of soil which is not covered with vegetation. The effect upon soil formation exercised by this climate may be threefold. Where there is a total lack of precipitation or only occasional rainfall (in deserts),

the rocks suffer only mechanical weathering, cracking to pieces, and being sorted and redistributed by the wind, but show no signs of any chemical weathering. Where there are recurrent rainy periods (steppes), the mechanical weathering is confined to the dry, lifeless period, and during the vegetation period the soil contains sufficient moisture to quicken chemical weathering and the decomposition of fresh material (at least near the surface), while the decomposition products, owing to the deficient character of the leaching, accumulate in the upper horizons. Very characteristic are the crust formations, consisting usually of $CaCO_3$ or gypsum ($CaSO_4.2H_2O$), found in the drier categories in the upper soil horizons. In the depressions lying on the border-line between these two areas, where the surface waters meet, we usually find saline efflorescences and arid saline or alkaline soils, which often form round salt lakes lying at the lowest levels. Thus in Hungary, in the district lying between the Danube and the Tisza, saline efflorescences are not uncommon in the soda soils in a dry summer, while at the lowest points of the hollows stagnant lakes are often found.

The arid zone itself is divided into the two main climate types known as *torrid deserts* (*BW*) and *steppes* respectively. The degree of air moisture is then the basis for a further differentiation into dry continental and humid littoral climates.

(c) *Temperate Warm Rainy Zone* (*C*).—This embraces the greater part of the European climate. Generally speaking, it is moderately warm and moderately damp; for that reason it forms the forest climate zone. It deviates from Zones *A* and *B* in that it possesses a decided winter season, the coldest month of which ranges in temperature from 18° C. to 3° C. On the boundary line nearer the Equator snow and frost are of very rare occurrence; while on the boundary line on the polar side they occur frequently every winter, though not so constantly as in climate zones *D* and *E*. Apart from these general characteristics there are numerous varieties of the *C* type depending on temperature differences and the quantity and distribution of precipitation.

KÖPPEN distinguishes three main types—*Cs*, *Cw* and *Cf*.

Type *Cs* is the sub-tropical or Mediterranean climate. It is characterised by a dry summer and a mild but damp winter. Here the vegetation has to pass through two periods of rest—a short winter and a longer summer period. The typical vegetation is evergreen bushes and trees (*e.g.*, laurel and similar trees found on the Adriatic coast).

Type *Cw* represents the variety of *C* which has a dry winter, and is therefore the opposite of *Cs*.

Type *Cf*—a moderately humid climate—is the most common variety of type *C*. Here we may distinguish a sub-type *Cfa*, which is characterised by a very warm summer (the average temperature of its warmest month being more than 22° C.), and to which KÖPPEN

gives the name "Virginian Climate"—though he makes it embrace in general the whole south-eastern part of the U.S.A. as far as New York on the north and St. Louis on the west, together with the southern parts of Japan and the eastern coast of Australia between latitudes 25° and 34° S.

Another sub-type in this category is type *Cfb*—a climate with a cool summer (also called "Beech-tree Climate"), the warmest month of which never averages as much as 22° C.

The whole *Cf* type, together with all its sub-types, belongs to the forest zone—a fact of great importance to the student of soil science, since standing forests have special effects upon soil formation. The effect exercised upon the chemical weathering of the mineral soil by the temperate warm climate is itself a very favourable one, even though it may not be so favourable as that exercised by the warmer humid climate. The climatic factors are also favourable to the formation of humus, the decomposition of which is not so rapid as in humid tropical zones. In the constantly moist soil of forests leaching must also be very considerable, and the mobile products of weathering and decay are removed from the upper horizons and in part accumulate in the deeper horizons. As a result in particular of the considerable leaching of univalent and bivalent basic cations released during weathering, the upper soil horizons become acid.

(*d*) *Boreal* (*Northern, Cold*) *Zone* (*D*).—A general characteristic of this zone is that it has a very cold winter with a continuous snow cover and a real summer—though often restricted to a very short period. The main difference between this zone and Zone *C* is that the average temperature of its coldest month is never higher than −3° C. It differs from the Arctic zone (*E*) in that the average temperature of the warmest month is never lower than 10° C. Thus Zone *D* lies between the two isotherms −3° C and +10° C. The melting of the snow and—in the warmer periods—abundant rainfall constantly supply the soil with moisture, and for that reason the natural vegetation of this zone consists of coniferous or deciduous forests. The summer heat ripens spring wheat in the northern, and autumn wheat in the more southern regions.

Here KÖPPEN distinguishes two main types—*Dw* and *Df*. The former he calls "trans-Baikal"; its external characteristic is that in it dust and clear skies are confined to the cold winter-time.

Type *Df* differs meteorologically from *Dw* in that the precipitation is distributed over the whole year, there being no definite dry season. This is of minor importance to the vegetation, since the climatic difference falls chiefly in the period of hibernation, when the sap circulation of the plants is suspended. A much greater difference in vegetation is caused by the circumstance that as we approach the Equator the summer gets warmer

and longer, while as we approach the Poles it gets shorter and cooler.

From the point of view of soil formation the conditions of chemical weathering are less favourable in Zone D than in Zone C, though leaching is at least as intense and, indeed, relatively more complete. As a consequence, in Zone D we find eluviated soils more frequently, the leaching also being more complete. During the winter the soil too rests for a while, the length of this hibernation depending upon the extent and time of freezing.

(e) *Arctic Zone (E)*.—This zone lies beyond the range of tall trees, though the 10° C. isotherm does not coincide exactly with their northernmost limit. The cold of winter varies in degree, but a common characteristic is the cold summer, which precludes every kind of agricultural production. Here we shall distinguish two main types —ET (tundra zone) and EF (zone of eternal frost.) In the former there are still mosses and lichens, and—particularly in summer— many species of animals, chiefly marine. In these regions, if not too densely populated, man may still be able to provide the necessaries of life.

EF, on the other hand, is unsuitable for the life of vegetation or continental animals; and the only occasions when man may venture to enter them are scientific expeditions, when he is adequately provided with food. In the sea, however, fish exist since their food (plankton) can live under the ice. Similarly we find seafowl (gulls, etc.), which prey on the fish.

Zone E climate prevails not only in the arctic regions, but also in high mountain regions where we find mosses and lichens beyond the tree limit, while on the highest peaks there is eternal snow and ice. In climate E the soil is always frozen, the only difference being that in climate ET, during the period of summer insolation, the surface snow and ice melt, the water remaining above the frozen lower horizon. Then certain mosses and lichens may grow, and indeed sometimes an oasis will be found to have a flowering vegetation round it, though it does not produce seed. These soils are called tundras. The soils barely weather at all, and are almost permanently under water—or even frozen, so that reduction processes predominate.

In the zone of eternal frost, EF, where the average temperature of the warmest month is always below zero, not only is there an end to all life, but soil formation is also permanently suspended, for there is neither opportunity nor possibility of the chemical weathering of minerals or of humus formation or even of leaching.

Thus, when we consider the climatic types discussed above from the pedological and phenological points of view, we see that beginning at the Equator and starting from the weathered, fertile soils rich in humus of the primeval forests of the torrid zone, we pass through

the leached-out laterites of the savannahs to the dry steppes and then to the arid deserts, where in default of sufficient moisture vegetable life ceases and there is a suspension of soil formation. We then pass north and reach the steppe zone again, passing into the sub-tropical (Mediterranean) type of climate (*Csa*), with a rich evergreen vegetation, and where the long, warm and relatively dry summer favours the decomposition of organic substances and the oxidation of iron. Here we find typical red earths (*e.g.*, on the shore of the Adriatic, in the Gulf of Quarnero). Then in the moderately damp *Cf* type we are already in the world of beech forests and brown earths (France, Germany, the British Isles, Denmark). The Scandinavian Peninsula, apart from the lofty mountains, is the home of coniferous and birch forests where, except in the many peat regions, the majority of the soils are podsols. The tundras are confined to Northern Russia and Northern Siberia; while Greenland is in the world of eternal frost and has tundras only on its fringes.

3. Pedological Importance of Certain Important Climatic Factors.

Some investigators have recently endeavoured to find a simple expression relating climate to soil types. LANG, for instance, in 1915[*] and in 1920[†] suggested the so-called "rain factor" ("Regenfaktor") as a means of characterising climate as a soil-forming factor. This factor is obtained by dividing the mean annual rainfall by the mean annual temperature. For the effect of climate on the soil is determined not so much by the total rainfall as by the difference between the moisture precipitated and the moisture evaporated, as it is only this difference that remains in, and therefore acts upon, the soil. It is, however, extremely difficult to determine the real evaporation values, but since within certain limits evaporation depends upon the prevailing temperature, LANG proposed to express the measure of evaporation by the average annual temperature. The application of this test is extremely simple, for we already possess very extensive meteorological data relating to average annual rainfalls and temperatures.

It is an easy matter to estimate the significance of LANG's rain factor in the light of what has been already said, knowing as we do how difficult it is to fix the limits of climatic zones simply on the basis of meteorological data. For LANG saw that if—in the temperate and tropical climates, on the limits of the arid and humid zones—we determine the relation of the mean annual rainfall to the mean temperature by plotting rainfall figures as abscissæ against temperature

[*] See LANG, R.: "Versuch einer exakten Klassifikation d. Böden in klimatischer u. geologischer Hinsicht" (Int. Mitt. f. Bodenkunde, Vol. V., 1915, p. 312).

[†] See LANG, R.: "Verwitterung u. Bodenbildung als Einführung i. d. Bodenkunde" (Stuttgart, 1920-6, p. 188).

as ordinates, we get an approximately straight line. This means that on the limits of the arid and humid zones the ratio of rainfall to temperature is about the same—viz., 40 mm. for each degree centigrade. For instance, where the mean annual rainfall averages about 400 mm., aridity commences the moment the mean annual temperature rises above 10° C.

LANG then—as shown in Fig. 2 below—connected the resulting values with the soil types.

The rain factor proposed by LANG has not met with the appreciation it deserves, though recently certain scientists have applied it with varying success to the characterisation of climate.
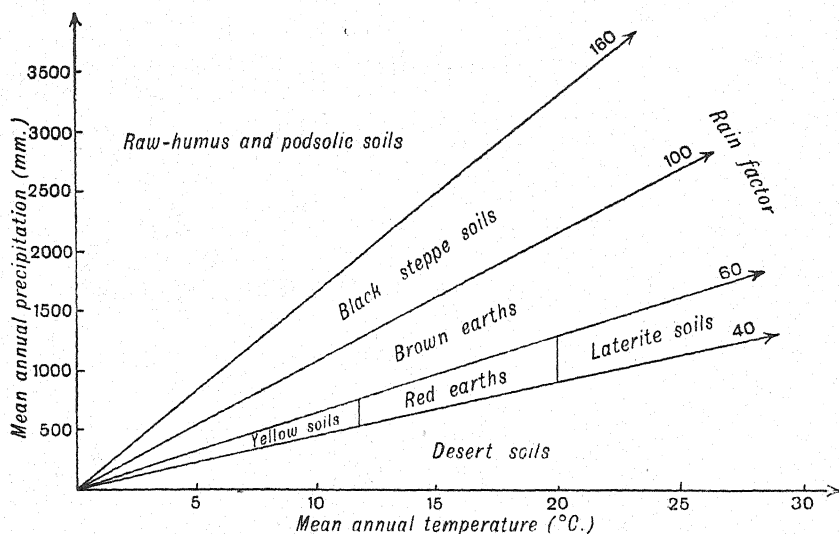
FIG. 2.

The same fundamental ideas are behind MEYER's "humidity factor" (the so-called *N-S quotient*), which "is obtained by dividing the mean annual rainfall by a coefficient expressing the mean deficit from saturation at the mean annual temperature."* The mean deficit from saturation is calculated by multiplying the vapour tension in millimetres of mercury by the relative deficit from saturation calculated on the basis of the local meteorological data (100 = mean relative moisture). The annual rainfall is divided by this figure to obtain MEYER's N-S quotient. JENNY states, for instance,† that in Sheridan (Wyoming) the mean annual temperature is 6·17° C., corresponding to a vapour tension of 7·06 mm. of mercury. The relative air humidity

* See MEYER, A.: "Über einige Zusammenhänge zwischen Klima u. Böden in Europa" (Chemie der Erde, 1926, p. 209).

† JENNY, H.: "Klima u. Klimabodentypen in Europe u. in den Vereinigten Staaten v. Nordamerika" (Soil Research, Vol. I., 1929, p. 183).

in the same place is 67·5 per cent.—*i.e.*, the yearly deficit of moisture is $100 - 67 \cdot 5 = 32 \cdot 5$ per cent. This latter figure must be multiplied by the value given above—*i.e.* $\dfrac{32 \cdot 5 \times 7 \cdot 06}{100} = 2 \cdot 29$ mm. is the height of mercury corresponding to the mean annual absolute deficit of moisture. This latter figure is then used to divide the mean local rainfall, which in Sheridan is 367 mm., so that MEYER's N-S quotient is $367 / 2 \cdot 29 = 160$.

The calculation of the N-S quotient is not so simple as that of LANG's rain factor, especially as we have relatively few meteorological data concerning the relative moisture content of the air. JENNY, however, found that when supplemented by the mean annual temperature MEYER's N-S quotient was more useful for characterising climates from the point of view of soil types than LANG's rain factor. The final results arrived at by JENNY will be found in Table XIII below.

TABLE XIII

	Humidity Factor N-S-Q.		Limit of the Annual Temperature Averages in °C.	
	Europe.	*U.S.A.*	*Europe.*	*U.S.A.*
Grey steppe soils	0-100	30-110	4-12	7-11
Light-brown steppe soils	—	60-120	—	6-11
Chestnut-brown steppe soils	140-170	100-180	4-12	8-12
Tshernosem soils	130-250	140-250	4-12	3-12
Limit of arid climate	about 200	220-250	—	—
Degraded tshernosems	250-350	—	—	—
American prairie soils	—	260-350	—	—
Brown earth (RAMANN)	320-460	—	4-12	—
Brown forest soils	—	280-400	—	6-16
Podsol soils	400-1000	380-750	- 4- + 7 or 12	4-10

Even if we presume that there is a certain definite soil condition corresponding to every N-S quotient and degree of temperature, we must not forget that the character of a climate does not depend upon these two factors only, and that the soil itself is the product, not of the climate only, but of other soil-forming factors too. JENNY's figures as given above cannot therefore be regarded as unconditionally valid and are not sufficient in themselves for the characterisation of local climate variations. For the characterisation of a soil it is, however, a great advantage to know the N-S quotient and the mean annual temperature, for they usually supply data which are more easily accessible and express climate in a far simpler form than KÖPPEN's formulæ.

OROGRAPHICAL (LOCAL) AND HYDROGRAPHICAL CONDITIONS AS SOIL-FORMING FACTORS

LOCAL orographical and hydrographical conditions are often of decisive importance for the development of different types of soil. It is difficult to separate these two factors since they are closely interdependent, orographical conditions being usually directly dependent upon hydrographical factors and conditions, and vice versa. By way of illustration it will suffice to compare a mountainous region of decided configuration, with its steep slopes and its perfect water drainage, with a flat territory which is apparently a perfectly smooth basin without outlet. In the former, the water that rushes down from the mountain peaks is continuously washing away the fresh soil cover of the slopes; whereas in the latter—in undulating regions—the water leaves behind all coarser debris and forms *definite deposits* in the flat middle and lower reaches of the rivers, where the fall of the water has decreased. Here the river builds soil; whereas in the former case it carries away what the other natural factors have created. Wherever on hillsides some sort of soil profile has developed it is usually imperfect, particularly in places under cultivation. The slopes are still better protected against erosion by closed forests, for the canopy breaks the active force of the rain, while the humus cover absorbs the water. In plains the orographical conditions generally result in one part being undulating and allowing the surplus water to flow off, while another part is level and has no outlet. Here the water stops, being partly absorbed in the soil and partly evaporating. The amount of percolation depends on the orographical conditions not only of the upper soil horizon, but in innumerable cases of the parent rock also. That is why importance attaches from the hydrographical point of view as much to the quality, thickness and stratification of the lower layers as to the orographical conditions on the surface.

My experiments in the irrigation fields at Békéscsaba (1902-1903) showed that the salt content of the alkali land did not correspond so much with the orography of the surface as with the undulation of the impervious clay found in the subsoil. Fig. 3 shows the average salt content of the upper horizon (0-180 cm.) of the Békéscsaba alkali land. At each point of intersection of the broken line on the map borings were made to depths of 5-6 metres, the depth and mechanical composition of each layer was determined, Fig. 4 showing the whole profile of the soil. Above the diagram showing the profile will be found the figures for the salt content of the different sections of the profile.

These figures show that the lowest points of the alkali land are not always the richest in salt. I found, on the contrary, that the highest point was the richest in salt, merely because the impervious clay layer there was nearest the surface—at a depth of about 180-200 cm. On the other hand, at points lying at about the same altitude but where the salt content was infinitesimal, the clay layer lay at a depth of 5-6 metres.

The example given above suffices to show the interdependence of subsoil and local hydrographical conditions; but at the same time we
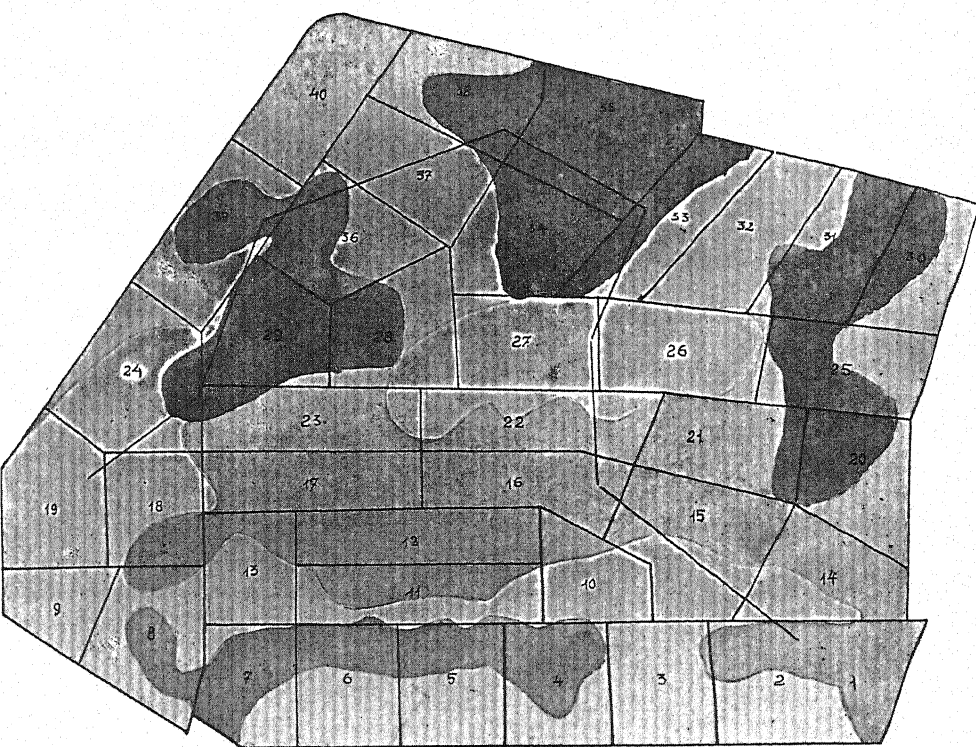
Total salt content: I. [   ] 0–0·10%. II. [   ] 0·10–0·25%. III. [   ] 0·25–0·50%.

FIG. 3.

see also that—particularly in flat districts, where orographical differences are relatively slight—the hydrographical conditions have particularly great influence upon soil formation.

(1) We distinguish three degrees of relief—macro-, mezzo- and micro-relief. *Macro-relief* is the division of the earth's surface into mountains, valleys, lowlands and plateaus. The effect of macro-relief on soil formation may be direct or indirect. Mountains exercise an important effect upon the climate of plains, while their height greatly influences

the climate of mountainous districts; the horizontal climatic zones of the great plains develop vertically here—*i.e.*, regionally—in keeping with the various mountainous regions. Changes of climate are followed by changes of vegetation, and the combined influence of both reacts
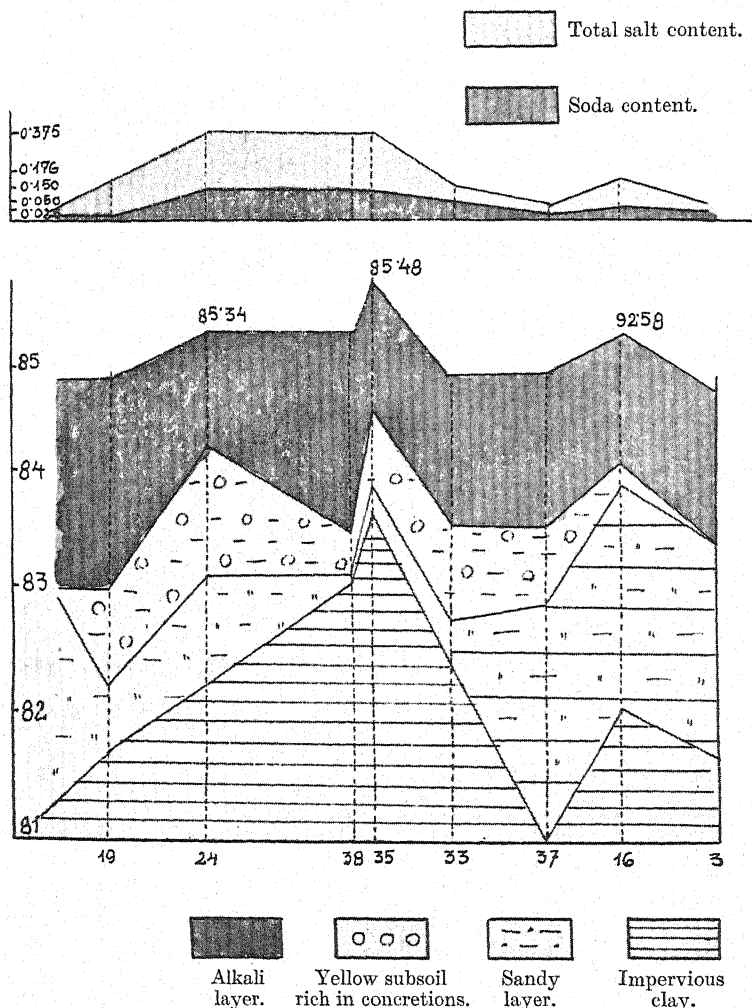
FIG. 4.

on the soils. As a result of erosion the typical development of soil profiles is very often inhibited, and consequently we cannot always determine the regional development of soils so typically as in plains.

The general orographical conditions of continents form peculiar climatic and soil zones. Within these zones, however, there are trifling

fluctuations of relief which, while having no important effect upon either the vegetation or the soil, are sometimes of decisive significance in determining the distribution of surface water and the moisture conditions of the soil. For instance, a slight subsidence of forest land may cause the accumulation of considerable amounts of water, the formation of peaty or swampy areas, and the death of the trees. In depressions in steppes we find cane-brakes, and on the fringes of the depressions salty alkali soils. These trifling fluctuations of relief are called *micro-relief*.

The *mezzo-relief* lies about half-way between the macro- and the micro-relief. It is illustrated by " downs "; here the differences of altitude and the angle of inclination of the slopes are not so negligible as in the case of micro-relief. Their effect is, however, by no means so important as that of high mountains.

(2) The hydrographical conditions are closely connected with the orographical and climatic conditions. The only hydrographical factors or conditions of interest to us here are those which are somehow or other connected with the water régime of the soil. Water which has percolated into the soil usually follows the law of gravitation and strives to reach deeper levels until it meets with opposition—viz., until either water absorption or the capillarity of the soil checks its course. Apart from these cases, it may happen that the water which has entered the soil finds an impervious subsoil layer or a rock in its way. There are two possibilities: either the water is diverted from its course and continues to run down the slope of the impervious surface until it reaches the sea or—where the impervious surface forms a closed basin in which the water accumulates—it goes on accumulating until it overflows the edges of the basin and joins some other water system.

Where the water rapidly drains from the soil (*e.g.*, in the case of gravel or coarse sand), we have a state of affairs unfavourable both to the vegetation and to soil formation, since the soil moisture very soon disappears and the soil dries up; in a moist climate the soil is readily leached. Soils of this kind are particularly liable to podsolisation.

CHAPTER IV

NATURAL VEGETATION AS A SOIL-FORMING FACTOR

NATURAL vegetation may be either more or less homogeneous, or variegated. The trees which form close forests—such as larches—prevent the growth of other vegetation over a considerable area. The leaf-cover of oak forests, on the other hand, is not so close, so that the rays of the sun are able to penetrate the foliage, offering numerous types of small plants opportunity of development. The richest plant association is that of the steppes.

The quality of a plant association is determined first by the climate

and then by the physical and chemical character of the soil. For that reason natural vegetation varies according to climatic zones or regions and according to the quality of the soil. Perhaps the most instructive in this respect is the natural vegetation of the great plains of European and Asiatic Russia, which are less subject to the influence of orographical or other environment conditions.*

1. Soil-Forming Effect of Parts of Living Vegetation Above and Below the Surface.

Living vegetation affects the development of soil in various ways; it is therefore expedient to distinguish the effect of the parts above from that of the parts below the surface. The former act primarily as a cover of varying density, according to which the protection it affords against winds, heat and cold or drought, varies. The thicker the vegetative cover on the earth's surface acting as a protection against the direct effect of air currents, and the more vigorous the resistance that cover is able to offer (as in the case of close forests), the less intense will be the evaporation and the changes of temperature. To this circumstance is due the fact that a plant-covered soil in general loses less moisture than a bare soil. There can be no doubt that the relative humidity of the air also plays an important part owing to the shade provided by the vegetative cover. In a forest, particularly in a close forest, the air is saturated with humidity, so that even in the heat of summer it is cool and relatively moist, while in open fields the heat of the sun and the movement of the winds make the air sultry and in consequence the rise in the temperature of the soil and the surface evaporation is intense. The quality of the vegetative cover may, however, have a decisive influence on evaporation.

Particularly where it forms a close cover for the soil, the living vegetation prevents surface evaporation, chiefly because it retards an increase in temperature and maintains a moist layer of air between the soil and the plant cover. Its roots, on the other hand, suck water —in larger quantities than would be the case in bare soil—from the depth to which they have developed. For that reason the level at which the soil dries up varies according to the type of vegetation or the depth of the roots. For instance, trees with deep roots seem to desiccate the soil from below; while the grass vegetation of steppes roots nearer the surface. Ultimately, however, the trees of a forest evaporate more water than grassy meadows or barren deserts. Forests also generally require a more humid climate than steppes. Steppes with a xerophytic vegetation of scanty growth can do with even less humidity, because the scanty character and peculiar properties of the vegetation (viz., narrow leaves, hairiness, thorns, resinous excretions, etc.) reduce the evaporation.

* See KELLER, B. A.: " Russian Progress in Geobotany as based upon the Study of Soils " (Leningrad, Acad. of Sciences, 5, 1927).

The living vegetation affects soil formation chiefly by modifying the moisture and heat conditions to suit its peculiar character, thereby practically transforming *the soil climate*. For the physical, chemical and biological phenomena occurring in the soil are affected not only by the external climate, but also by the climate in the soil itself where special conditions of humidity, air content and composition, and temperature prevail.

The subterranean parts of the vegetation also influence soil aeration, measured by the proportion of carbon dioxide in the soil air. For where the air is retained in the soil, the proportion of carbon dioxide increases. It goes without saying that the texture of the soil is also of decisive importance, for in loose sand or in gravelly soils the very character of the soil makes the process of aeration more rapid than in loamy or clayey soils. According to RAMANN,* deep-rooted forest trees such as beeches accelerate, while shallow-rooted forest trees such as spruces retard aeration.

The increase in the carbon dioxide content resulting in a decrease of the oxygen content of the soil air on the one hand shifts the soil reaction in the direction of acidity, and on the other enables the reduction processes to assert themselves.

Another essential effect exercised upon soil formation by the subterranean parts of the vegetation is the loosening of the soil caused chiefly by the fine root hairs separating the soil particles. This loosening effect is in evidence chiefly in that horizon in which the whole soil layer is interwoven with root hairs; *in the case of steppe vegetation it is the upper horizon and in the case of forests the lower horizons that are loosened by the action of fine roots.*

2. Soil-Forming Effect of Dead Vegetation (Humus Formation).

The dead vegetation supplies the bulk of the organic matter of the soil—of what is loosely called humus—or at any rate supplies the basic material. The smallest plant-cover—lichens and mosses—mingles its dead matter with the débris of rocks and supplies the first (original) organic matter of the rock débris washed down from high mountains. Grasses and tiny foliaceous plants augment the organic matter of mineral soils, not only by the addition of the organic matter accumulated as a cover on the surface, but also by the addition of their dead roots. The fallen leaves of bushes and trees form a thick cover on the surface of the soil which, as already stated, protects the soil against sudden changes of temperature and against the effect of evaporation. The root hairs reaching down to the deep layers also die in time, new ones being formed in their place, a process which in its turn constantly adds to the organic matter contained in the lower horizons. In all soils alike the amount of the organic matter changes in two ways:

* See RAMANN, E.: " Bodenkunde " (Berlin, 1911), p. 454.

it is either increased by the addition of fresh organic waste matter or is decreased as a consequence of constant decomposition or leaching out. Where the two processes are in equilibrium, there is neither increase nor decrease; where the constant increase of the dead organic matter exceeds the decrease, we find an accumulation of organic matter; and where decomposition and leaching of the organic matter exceeds the increase, there is a constant decrease—in extreme cases causing the eventual complete disappearance of organic matter (*e.g.*, in laterite soils).

3. Effects of Type of Plant Formation.

The vegetation growing on the soil exerts a specific influence on soil formation; hence have arisen such terms as " beech soil," " oak soil," " conifer soil," " heath soil," " wet meadow soil," " tundra soil," " steppe soil," " dry desert soil." I shall now discuss the particular soil-forming effects of certain more important plant formations.

(*a*) *Effect of Spruce on Soil Formation.*—This tree (*Picea excelsa Lk.*) is one of those requiring the most humid climates. Its soil is always wet on the surface and tends to the formation of acid humus; the water percolating through it is also acid and causes an intensive leaching out of the upper horizon. In the horizon containing the feeding roots the soil becomes less moist (as a consequence of the absorption of water by the roots), the solutions become more concentrated and the colloidal dispersions precipitate. The latter first form a dark brown accumulation horizon, which as it passes downwards changes to a rusty brown due to coagulated ferric hydrate. The coagulated colloidal materials then cement the soil particles which are, however, once more partly separated into aggregates by penetrating root hairs, while the withdrawal of the water produces irregular (nuclear or polygonal) aggregates, which form the typical structure of the accumulation (B) horizon characteristic of forest soils. Below this horizon we sometimes find what is called iron hardpan, often forming an impervious layer. The next layer is the parent rock (see coloured annex (Plate IV), profiles 1 and 2).

I do not propose to deal in detail with the soils of the other conifers; for, though they differ in respect of requirements and of root formation, they all form closed units and develop similar soils to those of the spruce.

(*b*) *Effect of Beech on Soil Formation.*—In many respects the beech is the exact opposite of the spruce; for it is deep-rooted and penetrates deep into the soil, while its humus cover is loose and as a rule not acid. Beech also prefers a moist climate; its foliage is dense, and consequently the soil surface is constantly moist, not being subject to direct insolation except in winter and spring, when the leaves have fallen. This accounts for the poor quality of the undergrowth, which only appears in early spring.

The moisture percolates through the interstices of the soil until it is

absorbed in the deeper horizons by the rich network of suckers to be subsequently evaporated by the foliage. The soil is therefore constantly washed through and leached out by water. Under favourable climatic conditions the leaf-fall covering the soil decays rapidly, for its loose and humid character is favourable to bacteria and earthworms, which together produce good mild humus. This is one of the ways in which brown forest soils are formed.

On the other hand, where the climatic conditions do not favour a rapid decomposition of the leaf-fall, we may find in beech forests also an accumulation of acid humus, or even of dry peat.

(c) *Effect of Oak on Soil Formation.*—The oak is also a deciduous tree, its roots and suckers penetrate deep and help to loosen and aerate the soil and subsoil. Mature oak forests are usually not closed, the sun shining through in places where bushes and low herbaceous plants and grasses thrive, eventually interweaving the upper horizon with roots and thus preventing the formation of raw humus.*

(d) *Effect of Heather (Calluna vulgaris) on Soil Formation.*—This plant—the " Heide " of North Germany—grows on any kind of soil, but is usually found on poor soils.† An abundance of moisture is not injurious to it. The root hairs of the plant form a very dense tissue leading to the formation of a dry peat similar to that found below the humus cover of the spruce. The soil becomes compact and impervious, and heather is thus very likely to induce peat formation.

(e) *Effect of Steppe Vegetation on Soil Formation.*—It goes without saying that the soil is affected not only by the several plants but by the steppe plant formation as a whole. The fine rootlets of the grasses spread thickest in the surface horizons. As a consequence of the arid climate the soil dries periodically; the grass vegetation becomes parched, then revives and in winter hibernates. The surface horizon crumbles, and the dead vegetable particles rapidly decompose, the conditions prevailing in the well-aerated, rich upper horizon being very favourable to bacterial life. The rays of the sun come into direct contact with the soil, particularly in dry seasons, when there is no vegetative cover. So long as the soil contains sufficient humidity, the heat accelerates decomposition; then the process ceases. The degree of aridity governs the fluctuations in the luxuriance of the vegetation and in the quantity of humus formed. The quantity of humus decreases with the depth. The interstices between the decayed vegetable particles make the soil porous, while the lack of humidity prevents the formation of clay. The slight humidity and the looseness of the surface soil are favourable to rodents (*e.g.*, field mice, moles, etc.), so that the profiles of steppe soils are often found to contain the holes and skeletons of these animals. A typical steppe soil profile of this kind is shown in the coloured annex, profile 7.

(f) *Effect of Wet Meadow Vegetation on Soil Formation.* — The

* See RAMANN, E.: *op. cit.*, p. 467.
† See GRAEBNER: " Heide Norddeutschlands," p. 143.

vegetation of wet meadows, though differing botanically, resembles steppe vegetation in its effect upon soil formation in that it also interweaves the upper horizon with its fine rootlets. The plants, however, require continuous abundant moisture. In soils belonging to this category the formation of acid humus is by no means a rarity, and even peat formation is not unknown.

(g) *Effect of Peat Vegetation on Soil Formation.*—We cannot deal in detail with the various peat associations. From the point of view of pedology the only types of vegetation of importance in this connection are those of the two main categories—low-moor or fen peat (*Phragmites* and *Carices*) and high-moor peat or bog (various species of *Sphagnum* and *cotton grass*).

Low-moor humus is rich, high-moor humus poor in bases; consequently, high-moor peats are usually very acid and deficient in plant nutrients, while low-moor peats are practically neutral and well supplied with plant nutrients.

CHAPTER V

ANIMALS AS SOIL-FORMING FACTORS

THE animal world is also to a certain extent directly dependent upon climate, though it is more closely dependent upon natural vegetation and soil conditions. The animal world, in its turn, exercises an influence upon both soil and vegetation. What we are interested in here is the influence exercised by animals upon the soil and soil formation, that exercised by them upon the vegetation interesting us only indirectly if it reacts upon the soil.

The animals which play a rôle in soil formation may in general be divided into two groups—(1) those living in the soil, and (2) those living on the surface of the soil.

1. The Rôle of Animals Living in the Soil.

The animals living in the soil belong to very diverse genera, but from a pedological point of view the zoological classification is quite unsuitable. RAMANN has divided the animals living in the soil into the following groups:

(1) Those which live permanently in the soil, only periodically coming to the surface.

(2) Those which only spend a certain phase of their lives in the soil.

(3) Those which in general live on the surface and only have their homes in the earth.

We are best acquainted with the rôle played by earthworms in the formation of the soil, and may take them as typical examples.

All scientists agree that by their mixing and cementing into small aggregates the earthy particles and the vegetable waste and other organic matter the earthworms make the structure of the soil crumbly and permeable to water and air, thereby exercising a very considerable effect upon soil reactions and biological phenomena. DARWIN, MULLER and WOLLNY believed that by passing these materials through their bodies earthworms induce further chemical reactions in respect of mull formation.

Another important group of soil-forming animals includes the various genera and families of rodents living in soils such as the common mole (*Talpa europea*), which is found everywhere in Central Europe and which has small eyes; the blind mole (*Talpa cœca Sav.*), which lives in South Russia and has no eyes; the European son-slik (*Spermophilus citillus L.*), common in the Hungarian Lowlands; the hamster (*Cricetus frumentarius*); the great mole rat (*Spalax typhlus*); the bobac marmot (*Arctomys bobac*); and the several kinds of mice. All these animals are rodents living in the earth mostly on vegetable substances.

Most of the rodents mentioned above live in steppe soils; they burrow sometimes to a depth of 5 feet and contribute largely to the natural mixing of steppe soils. Russian students when identifying steppe soils always search for skeletons or burrows of rodents ("crotovines").

The natural vegetation forms a plant association characteristic of the soil; similarly *the natural fauna of a given soil type—in particular the animals living in the soil—also forms an association related to the quality and the whole biological condition of the soil*, the several members of the association being living factors dependent upon one another, upon the vegetation and micro-organisms, and upon the chemical and physical character of the soil. *No biological characterisation of soils can be complete until we are fully familiar with the causal inter-dependence of the whole cosmos of the soil.*

2. The Rôle of Animals Living on the Surface.

The soil-forming effect of the animals living on the surface is still less known to us than that of the animals living in the soil. This fact has a natural explanation. The natural animal world living on the surface usually changes considerably the moment human beings settle in the region. The difficulty which we have to face here is that, while out of consideration for his own vital purposes man favours or exterminates certain animals, introducing others in their place, the influence exercised by the latter is never the same as that exercised by animals living wild. As a consequence, on this point—even more than in the case of animals living in the soil—we are dependent upon a few outstanding observations and upon the records of experienced scientists. RAMANN, who began his career as a student of forest soils, records many interesting observations of the kind proving that

this outside animal world is also of importance as a factor in the formation of soils and of the natural vegetation.*

RAMANN characterises as of great importance from the point of view of forestry the grubbing work of wild boars, and he suggests that in places where today the wild boars are becoming extinct, the raw humus cover of the forests should be periodically grubbed by herds of tame pigs. Grazing animals in general tend to increase the aeration of forest soil unless the grazing is excessive. Animals living in the open also leave their excrements on the soil, thereby furthering its metabolism. Today this refers only to a very reduced area of forest land—that of the primeval forests still extant. There can be no doubt, however, that in former days the grassy steppes and prairies had their own wild animals, which grazed and lived and died there until man came and exterminated them.

CHAPTER VI

MICRO-ORGANISMS AS SOIL-FORMING FACTORS

IT was the great French *savant* PASTEUR who first pointed out that if there were no microbes there would be an end to all organic life, since the dead organic matter would not decompose into simple compounds giving rise to new plant nutrients and new organic life. It is in the soil that this bacterial activity is chiefly carried on, and what interests us primarily is the actual rôle played by the micro-organisms in the characteristic formation of soil. This rôle is indirect rather than direct, for micro-organisms co-operate in soil-formation chiefly by gradually decomposing the dead (vegetable or animal) organic matter entering the soil and by giving a special character to the organic matter—the so-called *humus*—of the soil.

1. Micro-organisms of the Soil.

Twenty-five to thirty years ago, when speaking of soil micro-organisms, people still treated them as belonging to the field of soil bacteriology, although as far back as 1897 WOLLNY, in the work referred to already, had, when speaking of the formation of humus materials, spoken definitely of micro-organisms, which in his book are made to include moulds and yeasts.† Indeed, before WOLLNY, PASTEUR had already ascertained that vineyard soils contain wine yeast.‡

* See RAMANN, E.: *op. cit.*, p. 494.
† See WOLLNY, EW.: "Die Zersetzung d. org. Stoffe," Heidelberg, 1897, pp. 44-99.
‡ See LABORDE, J.: "Cours d'Œnologie," Paris, 1908, pp. 88-91.

As science stands today, we may group the micro-organisms of the soil as follows:

Plants ————————————————————→ *Animals*

Algae   Yeasts and Moulds   Actinomycetes   Bacteria   Protozoa

Each of these groups divides into several subgroups, with which I do not for the moment propose to deal. By way of information on this point I have given in Table XIV. the relevant Rothamsted data as found in RUSSELL's work.*

TABLE XIV

		Number in 1 g. Soil.	Approximate Weight per Acre.		
			Living Organisms.	Dry Matter.	N.
			lb.	lb.	lb.
Bacteria	max.	45,000,000	50	2	0·2
	min.	22,500,000	25		
Ciliatæ	max.	1,000	—	—	—
	min.	100	—	—	—
Amœbæ	max.	280,000	320	12	1·2
	min.	150,000	170		
Flagellatæ	max.	770,000	190	7	0·7
	min.	350,000	85		
Algæ	max.	100,000	125	6	0·6
	min.	—	—	6	0·6
Fungi	max.	1,500,000	1,700	60	6·0
	min.	700,000	800		
				93	9·3
				= 4 parts N to 1,000,000 parts soil.	

This Table shows that the number of bacteria is far in excess of, though their weight is far less than, that of the other micro-organisms, which, though smaller in number, are much larger in size, though still less than that of the larger organisms living in the soil. On the basis of a rough calculation LÖHNIS estimates the weight of the bacteria contained in a 25 centimetres thick layer of (medium pasture) soil 1 hectare in area (weighing 4,000 tons) at 400 kilogrammes and that of the other organisms living in the soil at 600 kilogrammes, showing thereby that a layer of soil 25 centimetres thick has to support 1,000 kilogrammes of living organisms per hectare.† However, since under favourable

* See RUSSELL, E. J.: " The Micro-organisms of the Soil," London, 1923.
† See LÖHNIS, F.: " Die Kleinlebewesen d. Bodens. *Aeroboe, Hansen* u. *Römer*," Handbuch d. Landwirtschaft (Berlin, 1929), Vol. II., p. 42.

circumstances the bacteria are able daily to decompose matter representing a quantity 100-1,000 times their weight, presuming that the average content of organic matter is 3 per cent., the 400 kilogrammes of bacteria present in 4,000 tons of soil have to deal with 120,000 kilogrammes of organic matter—*i.e.*, with a quantity 300 times their weight. This quantity could be decomposed by the bacteria in one to two days. The fact that this does not usually happen is due, not to the lack of bacteria, but to the resistance of the organic matter of the soil and to other circumstances. LÖHNIS illustrates this capacity of the bacteria by showing that the relative surface of the bacteria is very considerable, and he points out that, since the living organisms are in touch with the outside world only through their surfaces, their activity increases in proportion to the area of the surface.

The fact that the bacteria are able to perform the lion's share of the work of transformation is due not only to the extensive area of their surface, but also to the many-sided character of their activity. Bacteria usually carry out these chemical transformations by the aid of specific agents known as *enzymes*, which, as is well known, are organic but lifeless agents (*organic catalysers*), such as, for instance, the digestive secretions or the diastase of malt.

Soil contains some micro-organisms which decompose and others which synthesise organic matter. LÖHNIS divides the micro-organisms occurring in the soil into three main groups: (1) Organisms which either decompose or synthesise carbonaceous substances; (2) organisms which either decompose or synthesise nitrogenous compounds; (3) organisms transforming mineral compounds. These three large groups include all the micro-organisms to be found in soil.

The micro-organisms living in the soil are able to bring about a full cycle of organic substances even in their own microcosm; for most of the bacteria which decompose the best-known chemical compounds found in the soils are accompanied by other bacteria synthesising the same compounds. LÖHNIS outlined only two cycles of the kind:* these cycles are shown in Figs. 5 and 6.

Although these cycles of carbon and nitrogen compounds are the most important, we could construct similar cycles for the sulphur and phosphorus compounds—and indeed probably for the other constituent elements of the soil which take an essential part in synthesising the bodies of the micro-organisms (*e.g.*, K, Ca, etc.). However, here too—as I pointed out when dealing with the rôle of the animals living in the soil—we must not only familiarise ourselves with all the details of these processes, but also recognise that the decisive fact for the formation and character of the soil is not these separate processes, but *the equilibrium of all the interacting micro-organisms.* As we have seen already, certain types of soil formation depend upon the presence of definite vegetable and animal associations; in the same way the micro-organisms of the soil as a whole impart a

* See LÖHNIS, F.: *op. cit.*, pp. 54 and 59,

FIG. 5.—FORMATION AND DECOMPOSITION OF ORGANIC
CARBON COMPOUNDS.

FIG. 6.—THE CYCLE OF NITROGEN.

1. Decomposition of protein.   2. Ammonification.   3. Nitrification.
4. Nitrate reduction.   5. Ammonia- and amide-assimilation.   6. Nitrate-
assimilation.   7. Denitrification.   8. Decomposition of ammonia.   9. Fixation
of nitrogen.   (-- -- -- --≫ Processes of not thoroughly known character.)

certain typical character to the soil, which is the product of the
symbiotic and metabiotic co-operation of all the micro-organisms
found therein. The result of this co-operation is seen in the chemical
transformations effected by them.

2. The Most Important Chemical Transformations Effected by the Micro-organisms of the Soil.

Without entering into details we shall discuss those characteristic
transformations in the course of which the dead organic matter
entering the soil is decomposed and the humus material characteristic
of soil comes into being. WOLLNY divided the decompositions of
organic matter occurring in soils into two main groups. The first he
called mouldering or eremacausis (in German " Verwesung "), the
second he called putrefaction (in German " Fäulnis "). These
two main types of decomposition of the organic substances of soils
might be called aerobic and anaerobic decomposition respectively.
These two processes are usually found combined in soils, and it would
almost be better to say that the two processes go on simultaneously
but not in equal measure, implying that the difference between the
various soils consists in the different relative intensities of the two
simultaneous complex processes. Biologically speaking, it is a whole
complex of metabioses.

The principal chemical transformations will now be discussed in
detail.

The dead vegetable and animal organic substances consist mostly
of the following compounds:

(1) Water soluble carbohydrates (sugar, etc.) and their water
insoluble but easily hydrolysable products (starch, inulin, glycogen,
etc.).

(2) Vegetable fibre substances (cellulose, lignin, hemi-cellulose,
pectins).

(3) Proteins and various amides.

(4) Glycerides (oils, fats, lipoides).

(5) Dye substances (chlorophyll, hæmatin).

(6) Ash.

Some of these decompose rapidly and completely, others are more
resistant, and others again are too resistant. Sugar substances are,
for instance, relatively easily and rapidly decomposed by soil micro-
organisms—not only into the ethyl alcohol and carbon dioxide natur-
ally resulting from the organic fermentation, but also possibly into a
whole series of organic acids such as acetic, lactic, butyric, oxalic
acids, etc., which are also not final products, but decompose still
further until they too eventually produce carbon dioxide and water.
Actually, sugar substances and starch are but rarely found in soils,
while of the acids mentioned above only very slight traces have been

found. Cellulose is far more resistant. It constitutes the bulk of the vegetable fibre of plants and offers an effective resistance to the chemical agents also, *i.e.* weak acids and alkalies. Nevertheless, in soils—except peat soils—very little cellulose is found. This is due to the soils containing very large numbers of micro-organisms which decompose cellulose. SCHRÖDER computes that roughly 35 billion kilogrammes of cellulose are formed on the earth every year; this quantity would accumulate in huge masses if Nature had not provided for its decomposition. A study of the already extremely rich scientific literature relating to cellulose fermentation shows that, although the chief rôle in the decomposition of the cellulose in the soil is played by aerobic and anaerobic bacteria alike, there have also been found in the soil several kinds of cellulose-decomposing moulds (*Aspergillus oryscæ, Aspergillus Wentii, Aspergillus cellulose*) and other fungi (particularly the *Merulius lacrimans* and other *Polypori*).

Lignin, a by-product of cellulose, is still more resistant in soil, a fact that is particularly surprising since it is easily decomposed by chemical reactions in the laboratory and, moreover, probably undergoes various changes in living plants. By bacteriological experiments several scientists have shown* that when lignin and cellulose are subjected to the action of micro-organisms, the cellulose usually disappears very rapidly, whereas the lignin remains. It does, however, undergo certain changes—*e.g.*, it assumes an acid character and becomes soluble in alkaline solutions. *This is the origin of the theory that lignin is the real parent substance of humus materials.*† It will be the business of future research to show whether humus is a modified form of lignin or whether it consists of humus compounds originating from lignin or of new materials formed by the interaction of carbohydrates and amides furthered by the activity of micro-organisms. What we do know is that in nature humus is very often found in soils in typical forms and with characteristic peculiarities. In the next section I propose to deal with these natural humus types.

3. Natural Humus Types.

RAMANN divided the natural humus types into the following four groups: (1) turfs; (2) mould (residue of decayed plants); (3) mull (excrements of animals living in the soil); (4) chemically precipitated humus materials.

The term *turf* as used in pedology means an organic vegetable

* See BRAY, M. W., and ANDREWS, T. M.: Journ. Ind. Eng. Chem., Vol. XVI. (1924), p. 137; WEHMER, C.: Ber. deutsch. Chem. Ges., Vol. XLVIII. (1915), p. 130; Brennstoffchemie, Vol. VI. (1925), p. 101; FISCHER, F., and SCHRODER, H.: "Entstehung u. chem. Struktur d. Kohle" (Essen, 1922); PRINGSHEIM, H., and FUCHS, W.: Ber. deutsch. Chem. Ges., Vol. LVI. (1923), p. 2095.

† See WAKSMAN, S. A.: Verhand. II. Komm. Intern. Bodenkundl. Gesellschaft, Budapest, Vol. A (1929), p. 188.

formation consisting of more or less humified materials *the original plant structure of which can be seen with the naked eye.*

The residue of decayed plants—known as *mould*—differs from turf in that the plant structure can only be seen with the help of a microscope.

The term *mull* was introduced by MÜLLER,* and from the fact that MÜLLER attributed the chief rôle in the formation of this material to the work of earthworms and animals in general, RAMANN uses the term to denote the excrements of the animals living in the soil and distinguishes between " earthworm mull " and " insect mull," etc. We must, however, distinguish between the real " mull "—the accumulation *en masse* of animal excrements—and, for example, the humus of tshernosems. The latter represent the final stage in the work of the micro-organisms as decomposers of organic matter. The actual composition of these materials has not yet been ascertained; but their behaviour allows us to assume that they are acid in character and are probably a mixture of several compounds. Some chemists absolutely deny the existence of these humic acids;† nevertheless it is indubitable that the absorption complex of the soil usually contains an organic part which, according to ODÉN,‡ HISSINK§ and KOTZMANN,|| possesses a fairly well-defined valency; to use the term employed by MICHAELIS, this material—even though it does not represent a simple chemical compound or acid—is a negatively charged colloidal material with an " acidoid " character. Now, we may distinguish three kinds of chemically precipitated humus—acid, neutral and alkaline—according to the degree of saturation with metal cations and to the nature of the latter. Neutral humus is mainly a humus complex saturated with calcium ; acid humus is more or less unsaturated (*i.e.*, it is a humus complex containing hydrogen ions); while alkaline humus—whether saturated or unsaturated—contains a larger proportion of sodium ions than usual.

* See MÜLLER, P. E.: " Studien über die natürlichen Humusformen " (Berlin 1887).
† See the papers contributed by A. BAUMANN and by A. BAUMANN and J. DI GLERIA to the Mitt. d. bayr. Moorkulturanstalt (1909 and 1910).
‡ See ODÉN, S.: " Die Huminsäuren." Steinkopff, Dresden and Leipzig, 1932.
§ See HISSINK, D. J.: Verhandl. der II. Komm. d. intern. Boderkundl. Ges. Groningen, 1926, Vol. A, p. 198.
|| See KOTZMANN, L.: Mezög. Kut., Vol. II. (1929), p. 537.

THE AGE OF SOILS: TIME AS A SOIL-FORMING FACTOR

TIME as a soil-forming factor appears in DOCUCHAIEV's original formula.* "Like all other living organisms, soils," says DOCU-CHAIEV, "are only comparable if of the same age—young, mature or aged." And in his first soil classification, which appeared as far back as 1886, Docuchaiev differentiated between normal, transitional and abnormal. On the basis of similar considerations SIBIRTZEV divided soils into zonal (those which are well developed) and azonal soils (those which are not yet developed). In both cases the unde-veloped soils were made to include fresh alluvial soils—such as the alluvial soils of rivers—and the coarse and drift-sand soils, which categories possess a common character due to there not having been time or opportunity to develop typically. This is what must have induced MARBUT and a few of his American followers to distinguish between "mature" and "immature" soils.† SHAW, indeed, has a special name for each of the several degrees of maturity,‡ his division being as follows:

1. Solum crudum (raw soil).
2. Solum semicrudum (young soil, only slightly weathered).
3. Solum immaturum (immature soil, only moderately weathered).
4. Solum semimaturum (semi-mature, already considerably weathered).
5. Solum maturum (mature soil, fully weathered).

There can be no doubt that there are degrees of development of the various soil types. Thus, as we shall see later on, the several processes of soil formation—podsolisation, alkalinisation, etc.—have their own phases of development, and we can ascertain to which stage of the type development, etc., any soil belongs. The terms used above, however, are rather inapt, since the development of soils is never

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* DOCUCHAIEV used the following equation to express the fact that soil is a function of various factors, $P = f$ (K, O, G, V), P here representing the soil itself as a product equivalent to a function of K (climate), O (organisms), G (parent rock), and V (age of the soil), f showing that the P-value is a function of these agencies. The original paper on this subject, written by DOCUCHAIEV in Russian, appeared in 1889 at St. Petersburg with the title "On the Theory of Natural Zones." *Cf.* NEUSTRUEV, S. S.: Russ. Ped. Investigations, Vol. III. (1927), pp. 4 and 30.

† See MARBUT, C. F.: Proc. and Papers of the First International Congress of Soil Science, Washington, 1927, Vol. V., p. 1.

‡ See SHAW, C. F.: *op. cit.*, pp. 36 and 74.

suspended. We cannot speak of any maturity of soil such as that of animals or plants, if only because the soil does not usually include the factors of its development. The genus and species of a plant tell us what to expect when we sow a seed or other propagative organ. In the case of the soil this is not so, for—as we have seen—the raw rock itself is only one of the factors of soil formation; it is the combined operation of other soil-forming factors entirely independent of that material that decides what kind of soil shall under given circumstances develop out of the raw rock material.

The formation of the soil does not come to a standstill even if it is well developed: podsols, for instance, may in time change into peat soils or steppe soils. From alkali soil we may get either acid, degraded alkali or regraded alkali soil. In such cases it is *quite impossible to ascertain which state of the soil is the end of the process of development.* And when a soil reaches a stage of stability, it has ceased to be a soil and has again become a rock.

It should be noted, further, that by " time " I do not mean an absolute period, but merely the stage of development.

<center>CHAPTER VIII</center>

MAN AS A SOIL-FORMING FACTOR

RAMANN was right when he affirmed that[*] man is one of the most effective soil-forming factors, since it is in his power to change and replace the natural flora and fauna of the soil.

It is true that pedological textbooks have had little to say about this very important soil-forming factor—a deficiency which is pardonable when we remember that man's activities as a soil-forming factor embrace the whole field of agricultural production (plant-growing, cattle-breeding, forestry, pomology, viticulture, market gardening, etc.). Indeed, certain chapters of applied pedology—*e.g.*, soil cultivation, soil reclamation, etc.—deal exclusively with the effect exercised on the soil by man. I must, however, insist upon the great importance of man as a soil-forming factor; for unless we take that fact into consideration, many phenomena will be in apparent contradiction to the conclusions drawn from certain soil-forming conditions.

Man's influence on soil formation varies according to his manner of cultivating the soil. In this connection we may distinguish three degrees of cultivation—primitive, extensive and intensive agriculture.

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[*] See RAMANN, E.: " Bodenkunde," 3rd ed., J. Springer, Berlin, 1911, p. 495.

1. Effect of Primitive Agriculture.

In primitive days the agriculturist lived by hunting, fishing and grazing. The first two occupations have barely any effect upon the soil, except that the hunters disturb the game living in forests and prepare clearings and shelters. For grazing we need pasture-lands, and have to destroy forests and noxious animals.

2. Effect of Extensive Agriculture.

Ever since men have been familiar with the advantages of arable cultivation, one of the chief reasons for the destruction of forests has been the desire to put forest land under the plough. Ploughing not only loosens the upper horizons, but also turns them over and mixes them. The first changes observable from a pedological point of view are the mixing of the upper horizons and the disappearance of the original soil structure. But the plough not only breaks and turns over the ploughed layer, it also compacts the lower horizon over whose surface it passes—in other words, below the loosened soil there is formed a more compact subsoil. The effect is enhanced by the illuviation of the rainfall, which washes down into lower horizons the finely dispersed substances which accumulate on and clog the upper layer of the subsoil.

We must not, however, assume that ploughed soil is looser in structure than the original forest soil was. Experience proves just the opposite. For, whereas in forests the soil is more or less protected against the silting effect of rain, on ploughed land every heavy rainfall is followed by silt infiltration and condensation of the soil. In the case of plants requiring to be hoed we may afford a temporary relief, but we cannot offer the protection given by the foliage or undergrowth of a forest.

The researches made by TIULIN* have provided figures proving that cultivation destroys the originally loose structure of the soil.

The movement of water in ploughed land is not the same as it is in forest land; for, while in the latter the water continuously runs downwards and the soil dries up from below, in the former the move-ment of the water is reversed during all dry periods and the water migrates to the surface and evaporates either on the surface or through the crop. The water, indeed, moves in the same manner as in steppe soils, this being the reason why ploughed forest soils sometimes change into steppe soils. This is naturally only possible in places where the soil has not—as a result of the effect of forest vegetation—been leached out to an extent preventing regradation.

It must not, however, be assumed that by changing the direction

* See TIULIN, A. TH.: Proceedings of the Intern. Soc. of Soil Science, Vol. IV. (1929), p. 51.

of water movement we save the plant nutrients of the soil. For those nutrients, though not leached out through the lower horizons, are taken out of the soil in the crops.

3. Effect of Intensive Agriculture.

The object of intensive agricultural production is to take out of the soil the maximum possible under given conditions. Where our sole object is to get the largest possible yields, we must endeavour to create the best possible conditions suitable to the development of the plants usually grown. That undoubtedly means putting the soil into the best possible condition physically, chemically and biologically; but equally it makes the greatest possible demand upon all the productive factors of the soil and requires the maximum of nutrient replacement and soil cultivation. Where intensive production is taken to mean an endeavour to reach a maximum earning capacity (that being in fact the object of true rational production), we shall find that that endeavour very often leads to an extremely one-sided and to a certain extent extensive system of agriculture. Exclusive wheat-growing, for instance, in a relatively short time causes exhaustion of the soil.

The system of crop rotation certainly does not exhaust the soil so rapidly, but in this case too, if the only objective is to enhance the immediate net revenue, the soil is bound to become exhausted unless it is treated not merely as a dead instrument, but as a living body which has to be tended, fed and developed, if we wish to preserve it for future cropping. It must not be forgotten that men—like unreasoning animals or natural vegetation—endeavour to exploit the natural properties of the soil to their best advantage. From this point of view, therefore, the effect of man upon the formation of the soil may be regarded as just as natural as that of the mole or of earthworms, which live their whole lives in the soil and cannot thrive except where the soil conditions are suitable. Man goes one step farther, for his intelligence enables him to subject to his will even those soils which in their original state do not satisfy his wants, thereby transforming their character and setting on them what we may call the seal of human intervention. This seal naturally varies according to the cultural, social and economic conditions in force.

To give instances: regions naturally dry are reclaimed by irrigation, while regions that are water-logged or peaty are reclaimed by drainage. The Dutch have driven the sea out of large areas, converting them into arable land by dyking. We Hungarians reclaim alkali soils by transforming them into calcium soils.

However, since the effect of man upon soils is a subject for soil technology, *we shall here merely emphasise the necessity of remembering, when dealing with the soil-forming factors, that man is at times one of the most effective—though he may also be one of the most capricious—of these factors.*

CHAPTER IX

THE PRINCIPAL SOIL-FORMING REACTIONS

So far I have discussed the effects that may be exercised upon the development of soils by each of several soil-forming factors. However, as Liebig showed that plants are not fed by one material only, but by all those necessary for their nutrition, in the same way we may say that soil develops not as the result of the influence of any single soil-forming factor, but as the consequence of the interaction of all the active soil-forming factors. In most cases we find a co-operation of all the eight factors dealt with above, the factors, however, varying both in the intensity of their effect and also qualitatively. Now, since eight different factors (even if at all times qualitatively and quantitatively the same) may produce a very large number of combinations, while their qualitative and quantitative variations may give rise to an endless series of degrees of action, it is obvious that to some extent every individual soil is different from every other one.

1. General Phenomena and Reactions.

The main reactions taking place in the soil may be grouped under the following heads:

(a) Dissolution and precipitation.
(b) Leaching and accumulation.
(c) Oxidation and reduction.
(d) Humus formation and decomposition.
(e) Formation and behaviour of the absorption complex.

I have grouped these general reactions in pairs; for the several pairs are interdependent, though being phenomena of opposing character. Dissolution must always precede precipitation. It is dissolution that brings into being what is called the *leaching process*—the migration of matter in soil formation—while *accumulation* is the result of precipitation. There is no accumulation without leaching, the only exception being the accumulation of organic matter in the upper soil horizon. Oxidation and reduction are very frequent and sometimes characteristic soil reactions.

Among the most important and most characteristic processes of soil formation are *humus formation* and *decomposition*. In the foregoing pages I have already spoken repeatedly of these processes; indeed, in dealing with the micro-organisms taking part in soil formation we familiarised ourselves with the principal kinds of natural

humus formation. What we have to do now is to gather together
into an organic whole the material scattered about in the several
chapters dealing with the different factors. For despite the fact that
the process is contributed to by the higher plants and animals, by
micro-organisms, and to some extent indeed also by man—these being
all factors differing in themselves and more or less independent of one
another—humus formation is nevertheless to be described as the
result of *a harmoniously coherent co-operation (biocœnosis)*.

There are two conceptions of humus substances. One school*
maintains that there are definite and specific humus substances,
describes how they are separated from the soil, their physical and
chemical characteristics and methods of determination; the other
school† denies that humus substances are specific chemical com-
pounds peculiar to soil formation, arguing that they are products of
the alkaline extraction of the soil and regarding the organic matter
found in the soil simply as the residues of the more resistant con-
stituents of dead organic substances. Probably the truth lies some-
where half-way. The results of microbiological activities entitle us
to presume that the lignin constituting the bulk of the organic matter
of the soil owes its preponderant accumulation to the fact that it is
the most resistant substance, that the substances soluble in water
are soon leached or exhausted, and that the proteins, celluloses and
hemi-celluloses are decomposed and serve as food and sources of
energy for the soil bacteria. Thus the decomposed organic com-
pounds once more produce a complex living organic substance, while
the bodies of the bacteria, which absorb practically all the nitrogen
in the soil and also a part of the phosphoric acid, once more begin to
decompose after the death of the bacteria. Quite recently WAKSMAN
devised a method‡ for the determination of the ligno-protein complex
in soils, which he calls the "*humus-nucleus*," assuming it to con-
stitute the bulk of soil humus.§ It seems also that the behaviour
of artificial ligno-protein is similar to that of soil humus. It would,
however, be premature to make any critical remarks until this method
and these hypotheses have been better tested and until we have had
time to form a considered judgment.

It is, however, indubitable that during the process of humification
in soils some kind of brownish-black substance is formed which may
be extracted not only by an alkaline solution but also by certain
neutral solvents, and which functions as a weak organic acid. A
detailed differentiation of humus substances (as elaborated by S.
ODÉN) will be found in the following table:

* See ODÉN, S.: " Die Huminsäuren," 2nd. Ed. (1922).
  † See WAKSMAN, S. A.: Verhandlungen d. II. Komm. Int. Bodk. Ges.,
Budapest, 1928, Vol. A, p. 195.
  ‡ See WAKSMAN, S. A., and STEVENS, K. R.: Soil Science, Vol. XXX.
(1930), p. 97.
  § See WAKSMAN, S. A., and IYER, K. R. N.: " Soil Science," Vol. XXXII.
(1922), p. 43.

TABLE XV

CHARACTERISTICS OF DIFFERENT HUMIC SUBSTANCES

Name.	Solubility in :			Salts.	Colour.	Special Characteristics.
	Water.	Alcohol.	Alkali.			
Humic coal ..	Insoluble and un-dispersible	Insoluble	Insoluble	Only adsorption compounds are known	Black	By fusion with alkali hydroxide salts of huminic acids are formed.
Humic acid ..	Slightly soluble, dispersible to a suspension	Insoluble, but slightly dispersible	Soluble	The alkali salts are soluble in water and dispersible in alcohol. The other salts are slightly soluble, but dispersible in water	Black and brown with reddish tint	The equivalent is about 340, the C content about 58 per cent.
Hymatomelanic acid	Slightly soluble, but readily dispersible to a suspension or colloidal solution	Forms true solution	Soluble		Brown with yellowish tint	The equivalent is about 250, the C content about 62 per cent.
Fulvic acids ..	Forms true, readily diffusible solutions	Forms true solution	Soluble	Most are soluble in water	Golden yellow	C content less than 50 per cent.

Huminic acids.

The humus complex behaves in the manner of a weak, insoluble organic acid able to absorb various cations; but, should the complex not find in the soil sufficient bases to permit the saturation of its free valencies by metal cations, the free valencies are occupied by hydrogen, forming a weak acid which imparts acidity to the soil too. The greater the amount of hydrogen absorbed in this manner, *the greater the degree of unsaturation of the humus and of the acidity of the soil.* This acidity is, however, only partly active, the extent of its activity being measurable by the hydrogen-ion concentration dissociated in the soil solution —*i.e.*, by the so-called pH value. The greater part of the absorbed hydrogen is not active—as in all other slightly soluble acids. This part constitutes the so-called latent acidity of the soil, which asserts itself either wholly or in part when the soil is brought into contact with neutral or alkaline salts or with oxides.

However, in the case of humus importance attaches not only to the degree of saturation or unsaturation, but also to the question which metal cations are contained in the saturated part. The condition most favourable to the quality of the soil is when the predominant cation absorbed in the humus is calcium; potassium may be useful as an easily available plant nutrient, but sodium is decidedly noxious. So far no definite opinion has been formed respecting the rôle of magnesium.

STEBUTT assumes that acid humus is an oxidation product of mild humus, an assumption supported to some extent by analytical research. According to data collected by ODÉN the humic acid present in mild humus contains 58 per cent. and the hymatomelanic acid 62 per cent. of carbon, while the fulvic acid present in acid humus contains only 55 per cent. A certain interest attaches also to the practical observation that mild humus under certain conditions may change into acid humus, whereas on the other hand soil containing acid humus—even if neutralised with lime—never becomes quite the same as an originally mild humiferous soil, genuine soil of that type being obtainable only by the formation of a new mild humus. It is commonly found that when acid peat soil, for instance, is neutralised by liming, the resulting soil, though it may be fertile, shows a rapid decomposition of the neutralised humus and deteriorates. This does not happen when we provide simultaneously for the formation of mild humus—*e.g.*, by the cultivation of leguminous and grassy plants or by the employment of a large quantity of farmyard manure—this being a method of enriching fen soil with matter containing mild humus. There are many who regard this as merely soil inoculation. There is something to be said for this view; for acid peat soils are usually poor in bacteria, whereas farmyard manure introduces a large number of useful bacteria into the soil. But farmyard manure also introduces into the soil valuable mild humus, which is at least as effective in improving acid fen soils as are useful bacteria. These practical observations also support the hypothesis that, even though

we are not yet sufficiently familiar with the chemical differences
between acid and mild humus respectively, we must regard acid
humus as a product of a further decomposition of neutral humus from
which the original higher type of humus cannot be reconstructed—
at least not with the scientific means at present available.

The most essential difference is in the circumstances of formation
of the two types of humus.   Mild humus is the characteristic product
of grass steppes, acid humus of acid forest soils or peats.   The vegeta-
tion of steppes is essentially xerophytic—*i.e.*, it consists of plants
which prefer an arid climate (*e.g.*, *Stipa penata*, *S. capillata*, *S.
Læsingiana*, *Festuca sulcata*, *F. ovina*, *Kœleria gracilis*, *K. cristata*,
Bromus inermis, *Poa bulbosa*), which live only in neutral or slightly
alkaline soils and make excessive demands on the plant nutrients in
the soil.   Hence, where the steppe vegetation is rich, the soil is by
nature rich, while this richness is not only protected but also augmented
by the steppe vegetation by the formation of mild humus.   Con-
sequently, the vegetation itself abounds in bases; and when it decays
there are sufficient bases present immediately to saturate the so-called
" mild " humus which is formed and which, on account of its base
saturation, STEBUTT* refers to as " basic " humus.   We may, indeed,
say that this humus was already saturated in the early stage of its
formation.   All that the soluble bases in the soil were able to do
was to equalise the actual conditions of equilibrium or to induce later
changes by base exchange.

Conditions are different in the formation of the acid humus of forest
or peat soils.   In the first place the trees themselves are poor in bases.
This is particularly true of conifers.   STEBUTT has shown that trees
in general require 2-4 times less mineral matter than grasses or cereals.†
The table below offers a few characteristic data illustrating this point:

					Total Ash Content of the Annual Increment (per Ha.).	
Firs (*Abies pectinata*)	..	..	..	..	65 kilogrammes	
Beeches	..	..	..	..	190	,,
Hay	..	..	..	..	320	,,
Wheat	..	..	..	..	240	,,

Now, since forest trees require a more humid climate than do steppes,
the soil is more easily leached—as indicated in a previous section.
So when it enters the soil the organic matter of trees is already
poor in bases, and the soil is generally also poor.   Consequently,
when the organic matter decays, the bases present are usually
insufficient for saturation.   Moreover, as a result of the processes of
decay, several intermediate oxidation products are formed which
increase the quantity of humic acids.   We can understand, therefore,

* See STEBUTT, A.: " Lehrbuch der allg. Bodenkunde," p. 195.
† See STEBUTT: *op. cit.*, p. 323.

that the humus formed under such conditions cannot be saturated and is exposed to further decomposition (*e.g.*, oxidation) that still further encourages the formation of humic acids. We know by experience also that acid humus contains colourless acid compounds (formerly called " crenic acid " and " apocrenic acid ") the alkali and calcium salts of which dissolve in water and migrate in the soil, whereas mild humus combined with calcium does not form compounds soluble in water.

To sum up, mild humus differs from acid humus not only in degree of saturation, but also as regards the circumstances of formation and in the chemical and physical behaviour of the respective organic compounds, which must be of entirely different structure; in other words, mild humus is a higher organic complex out of which acid humus may certainly be formed, while the reverse process is not possible. In this field there is still much to be done by research, and what we have stated above is all that experience at present enables us to affirm.

Alkali soils also contain saturated humus, but owing to the lack of experimental data we cannot decide whether the only difference between the saturated humus of these soils and that of steppe soils lies in their being saturated with alkali cations instead of with calcium.

And now we come *to the most characteristic and most interesting constituent of soils—the so-called absorbing (or " humus-zeolite ") complex.* We refer to this constituent as a complex because we are not acquainted with its exact chemical composition, but we do know that usually it contains a mineral and an organic part. In the mineral part the principal rôle is played by Al_2O_3 and SiO_2. These zeolitic soil constituents are formed during the weathering of the silicates of the mother rocks. We are not yet in a position to ascertain whether the substances of crystalline character recently found in colloidal fractions are identical with, or only supplementary ingredients of, the absorbing silicates. The organic part of the humus-zeolite complex and the circumstances of its formation have already been discussed.

From what has been said it may be seen that *the chemical composition of the absorbing complex itself enables us to distinguish three principal soil groups—viz., acid, neutral and alkaline soils—*a differentiation which is a material one, particularly *as it is based upon the causes of the reaction phenomena and not upon accidental manifestations of reaction* (such as *pH value, titration acidity*, etc.). As we shall see later on, this soil complex plays an important part in the formation of the various soil types. Its most valuable characteristic from this point of view is that *it contains a lasting record of practically all characteristic soil reactions.* For the fragments of raw rock that remain tell us only about the original state and show us only what has disappeared. A water extract of a soil contains the most mobile soil constituents, but most of these are leached during soil formation and are therefore not

easy to ascertain. The absorbing complex is not so mobile, and for that very reason remains in the soil; and its composition bears lasting impress of the leaching, accumulation and other soil reactions dealt with above which occur during soil formation. Thus, for instance, when the complex contains much absorbed sodium, we may be sure that at some time during its development the soil was infiltrated with sodium salts which later on were washed out, the sodium still remaining in the absorbing complex.

2. Typical Soil-Formation Phenomena.

The most familiar typical soil-formation phenomenon is the so-called *podsolisation.* The name is of Russian origin, but today it is used all over the world by soil scientists. It is usually in evidence in forest, wet meadow, and heath soils. A characteristic of podsolisation is that under the moist humus cover there develops a grey leached horizon (a so-called " *podsol* "), below which we find one or more *accumulation horizons* of a special polygonal structure, dark brown or ferruginous in colour. Below that is the original parent material, the upper horizon of which is often enriched with $CaCO_3$ washed out from the higher layers. At present we denote these three characteristic horizons by the use of capital letters, as follows:

(A) The podsolic or eluviated horizon.
(B) The accumulation or illuviated horizon.
(C) The parent material.

In many cases each of these horizons—and in particular the B horizon—divides into several sub-horizons according to the order of sequence in which, in their downward progress, the leached constituents precipitate.

Podsolisation is in reality the result of *soil-leaching in an acid medium.* Under the moist humus cover the upper horizon is percolated by a water solution enriched with CO_2 and humic acids, and therefore *acid* in character. This solution first washes out and carries down the readily soluble alkali salts and then the alkaline earth carbonates ($CaCO_3$ and $MgCO_3$) soluble in water containing carbon dioxide. The moisture acting repeatedly from above attacks the silicates, which undergo first hydrolysis and then further decomposition. The hydrolysis itself may be either total or partial.

The essential features of this process are shown most clearly by a hydrochloric acid extract of the soil and by the saturation conditions of the absorbing complex. Table XVI. shows the HCl extract of the soil profile of the Hüvösvölgy deciduous forest, while Table XVII. shows the T complex of the same profile.

From the hydrochloric extract we see that the $CaCO_3$ and the $MgCO_3$ contained in the parent rock has been entirely washed out of horizons

TABLE XVI

CHEMICAL COMPOSITION OF THE HYDROCHLORIC ACID EXTRACT OF HÜVÖSVÖLGY SOIL AS PERCENTAGE OF DRY SOIL

	Horizon.			
	A.	B_1.	B_2.	C.
Na_2O	0·39	0·41	0·44	0·35
K_2O	0·57	0·59	0·51	0·61
CaO	0·60	1·91	1·67	8·95
MgO	0·80	0·81	1·24	3·60
MnO	0·28	0·55	0·07	0·94
Fe_2O_3	1·59	2·59	2·97	3·41
Al_2O_3	3·75	4·69	7·50	3·03
SO_3	0·39	0·29	0·47	0·35
P_2O_5	0·06	0·08	0·13	0·12
CO_2	—	—	—	7·94
SiO_2 soluble in conc. HCl and 5 per cent. KOH	8·94	9·43	10·68	6·09
Loss on ignition	4·51	3·87	4·52	3·76
Insoluble	77·21	74·41	70·26	61·11
Total	99·99	99·63	100·46	100·27

TABLE XVII

RELATION OF EXCHANGEABLE CATIONS TO TOTAL ABSORPTION CAPACITY

Horizon.	T.	*Mg. Equivalents of Exchangeable Cations as Percentage of Total Absorption Capacity* (T).						S.	V.
	Mg. Equivalent.	Al.	Ca.	Mg.	Na.	K.	H.	*Mg. Equivalent.*	
A ..	34·62	2·60	13·30	18·10	1·85	6·35	57·80	14·62	4·22
B_1 ..	34·23	2·03	20·30	15·23	3·62	6·20	52·60	16·23	47·40
B_2 ..	36·16	1·43	29·50	9·68	3·79	7·00	48·60	18·56	51·40
C ..	32·90	0·00	49·60	9·74	5·10	6·36	29·20	23·30	70·80

A, B_1, and B_2. The Fe_2O_3, Al_2O_3 and MnO have been leached out of horizon A into horizons B_1 and B_2, where they have partially accumulated.

From the change in the absorbing complex we can see that the quantity of H equivalents is greatest (57·80 per cent.) in horizon A and smallest (29·20 per cent.) in horizon C. On the other hand, the

quantity of Ca cations is smallest (10·30 per cent.) in the A and greatest
(49·60 per cent.) in the C horizon.   In this case, in the acid medium
the H ions first displaced the calcium from the absorbing complex.
The magnesium, on the other hand, accumulated in horizon A, while
the quantity of the alkali cations is insignificant—so insignificant indeed,
that we cannot help concluding that either they were never absorbed
at all, or as a result of their mobility were more completely leached
than the Ca cations.   The size of the T complex is shown by the
total of the mg. equivalents in the first column.   We see that this
complex increased during soil formation in the parent material (C),
though its maximum is that contained in horizon B_2.   The S-value
expresses the total equivalents of exchangeable cations, V expressing
the degree of saturation :

$$V = \frac{S \times 100}{T}$$

The values of both S and V increase with the depth.   The increase of
S-value is the result of the acid leaching from above, for which reason
the concentration of free H ions is greater in the upper horizon than
lower down; this being due, in its turn, to acid moisture percolating
continuously down from the humus cover and taking up cations on
its way, thereby becoming more and more neutral.   This moisture be-
comes less and less acid, and its effect upon the cations of the absorbing
complex consequently weakens as it migrates downwards.   That this
is not a mere supposition is proved by the results of acidity investiga-
tions summarised in Table XVIII.

TABLE XVIII

ACIDITY OF THE HÜVÖSVÖLGY SOIL, BY DIFFERENT METHODS

Horizon.	pH (Quinhydrone Electrode).		Titration Acidity.	
	In Water.	In Normal KCl.	According to Daikuhara-Kappen with Normal KCl.	With Normal Sodium Acetate.
A	5·9	4·3	10·50	20·9
B_1	5·8	4·7	1·50	8·3
B_2	6·7	4·4	0·80	5·3
C	8·1	7·5	0·15	0·6

From the above data it may be seen that in the processes of podsol-
isation we find dissolution, precipitation and all the other elementary
reactions referred to above, manifesting themselves quite clearly.
The essential characteristic of podsolisation is leaching in an acid medium.
But the process of leaching in an acid medium is not confined to

podsolisation; peat soils, for instance, are also formed in an acid medium, but here the leaching process is usually accompanied by another—viz., *reduction, which is the chief characteristic of peat formation*. The phenomena to which the formation, migration and reoxidation of *ferrous compounds* in peat soils give rise are described by Russian scientists as " *gley* " formation.

Some scientists (*e.g.*, Gedroiz) regard laterite formation as a kind of acid leaching. Others again consider it to be the result of alkaline leaching—a theory which certainly seems supported by the quantity of SiO_2 leached. I shall deal more exhaustively with laterite formation when speaking of allites.

The second large group of soil-forming processes are those forming steppe soils—from the *black earths* (tschernosems) to brown, light brown and grey steppe soils. A common characteristic of these soils is that *the leaching medium is neutral or only slightly alkaline*, for soils containing calcium carbonate possess in themselves a reaction of pH 8. The principal feature of the processes of steppe soil formation is that there *the humus and trivalent metal cations do not move downwards*, as in podsolisation, and that *the soluble silicic acid does not migrate*. The bivalent cations (Mg and Ca) may move downwards or upwards in the form of carbonates or sulphates, and the univalent cations—in particular sodium—quite frequently accumulate in the lower horizons. The absorbing complex itself contains hardly any hydrogen; while most (not infrequently 85-90 per cent.) of the absorbed cations consist of calcium.

Finally, the common feature of the third large group of soil-forming processes is that *soil formation and leaching go on in the presence of abundant alkali salts*.

In all the soil-forming processes so far discussed we have seen that the alkali cations are leached out of practically the whole soil profile so thoroughly that they are not found in any quantity, either in a water-soluble or in an absorbed state. *The common characteristic of alkali and saline soils*, however, *is that in them the alkali cations—in particular sodium—have accumulated either in the form of water-soluble salts or in the absorbing complex—i.e., in an exchangeable state.* In the formation of saline soils we may distinguish four stages of development:

(1) Accumulation of alkali salts.
(2) Progressive penetration of absorbing complex by alkali cations.
(3) Leaching of alkali salts.
(4) Partial replacement of sodium cations of absorbing complex by hydrogen (hydrolysis).

The first stage of development consists simply in the accumulation in the soil for some reason or other of alkali salts, though without any important change resulting in the absorbing complex of the soil. These are *common saline soils* such as are found in all parts of the world in which the conditions are favourable to an accumulation of salts.

But where the salt concentration assumes proportions enabling the alkali cations to affect the absorbing complex of the soil in a manner leading, for example, to a partial replacement of the calcium by sodium cations, we find the beginning of alkalisation—*i.e.*, the transformation of the soil into a genuine alkali soil. We express the extent of this process (*degree of alkalisation*) by calculating the equivalents of the sodium ions in percentage of the sum (S) of the equivalents of the exchangeable bases. Soils in this stage of development are called *saline-alkali soils*.

The third stage consists in an almost complete leaching (up to 99·8 per cent.) of the water-soluble salts due to some natural or artificial circumstance. In such cases the soil continues to be alkali, only its salt content decreases to an extent not prejudicing its fertility. These soils might be called *washed-out* or *leached* (" *a-saline* ") *alkali soils*.

Finally, in the fourth stage the leaching of the alkali salts goes so far that their protective effect on the alkali cations contained in the absorbing complex ceases, while as a consequence of the further leaching *the alkali ions of the absorbing complex are, by hydrolysis, replaced by hydrogen*. Soils of this kind usually possess a slightly acid reaction and behave like soils formed under acid conditions; they were originally alkali soils and have retained their disadvantageous physical properties. They may thus be termed *degraded alkali soils*.

The principal soil-forming processes described above are to be found in nature in many forms and stages and are composed of different combinations of the simple soil reactions which have been discussed.
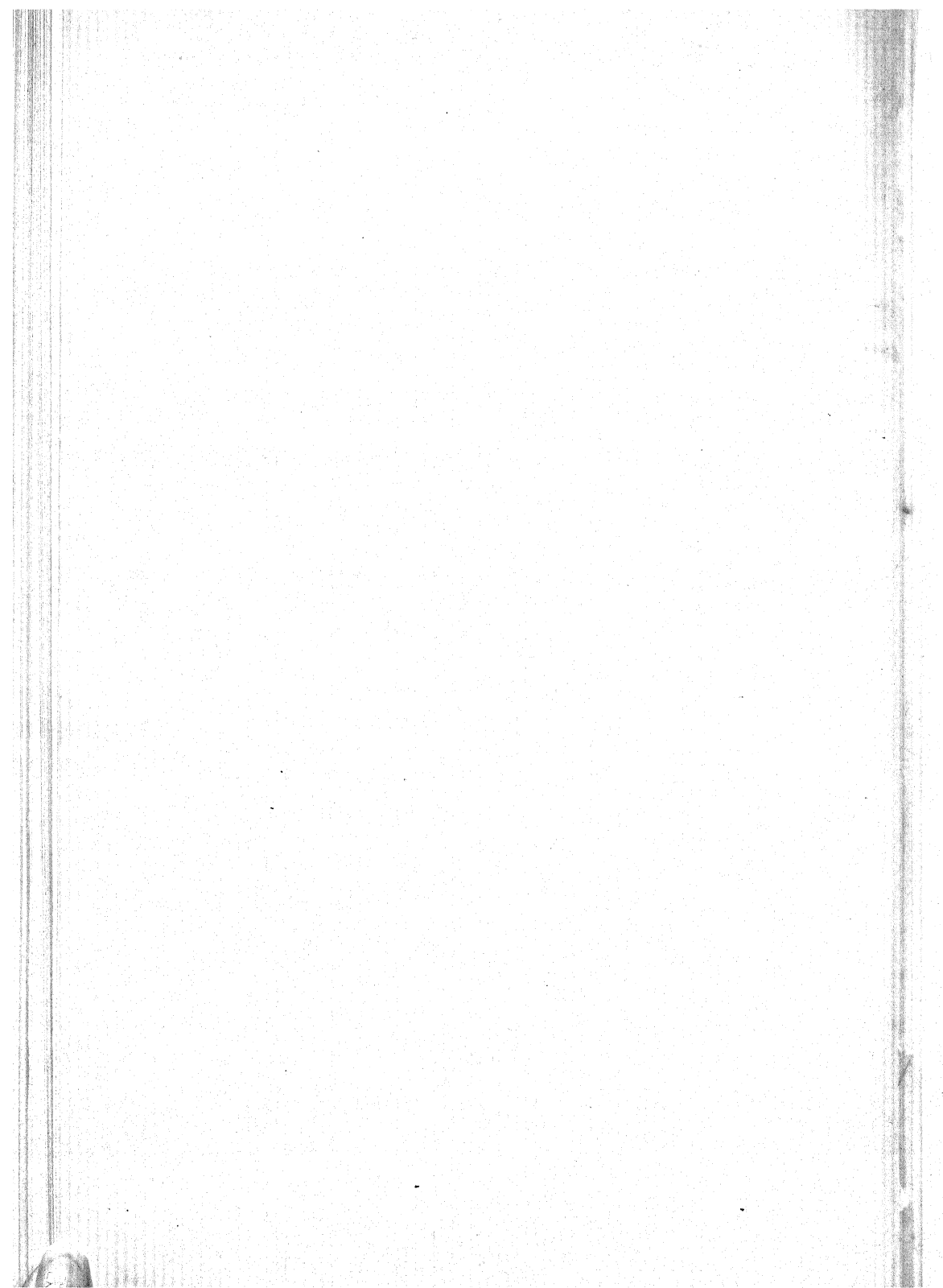
PART II

AGRONOMY

In the foregoing chapters we have dealt with the origin of soil, with soil-forming factors, and with types of formation. For a complete knowledge of the soil this is, however, not enough; indeed, the reconstruction of the past of the soil is in most cases uncertain and open to dispute.

Hence we must endeavour to ascertain soil-type characteristics by objective—*i.e.*, scientific—criteria, and we shall then be able to characterise the present condition of the soil and thereby discover its past and draw conclusions about its probable future.

The determination of types comes within the scope of *agronomy*, the branch of soil science which deals with the characterisation of soils. The characteristics of soils may be divided into four groups— those revealed by field studies, and physical, chemical and biological characteristics. Agronomy describes and systematises the nature and pedological importance of these characteristics, and thus leads up to soil classification—or rather to soil systematics. In the latter the genetic basis is insufficient, indeed it is very often quite uncertain, particularly when dealing with soil horizons of non-typical formation.

Agronomy is the oldest and most developed branch of soil science. Recent British pedological literature is particularly rich in works dealing with soil physics and soil microbiology. I have therefore thought it expedient to deviate from the procedure followed in my original work and to deal exclusively with soil surveying and the chemical characteristics of soils as being the main elements of my general soil system.

CHAPTER X

LOCAL SOIL SURVEYS

A PEDOLOGIST—whether chemist, physicist or biologist—*should never confine his investigations to the laboratory. Soils must be examined in detail in their natural environment,* otherwise there is every likelihood of drawing false conclusions. It often happens that a soil in its original state differs entirely in colour from the same soil when it reaches the laboratory. It is easy to understand, for instance, why a soil containing iron in the form of ferrous salts should change its colour by contact with the air. The change ensuing under such circumstances may be so complete as to prevent our detecting the original colour. Another peculiarly local characteristic is the natural structure of a soil, which cannot be ascertained except by examination *in situ*; for the moment we lift the soil out of its original position, the structure becomes more or less disturbed, often beyond recognition.

Owing to these and other similar circumstances local soil surveys are very valuable, and in many cases are indeed indispensable, particularly when it is a question of determining and mapping soil types. These soil surveys often include subsidiary studies of, *e.g.*, geological formation, meteorological phenomena, hydrographical and orographical conditions, etc., and various experiments carried out in the field. In the present chapter I must therefore deal with all these points, although the subject itself embraces very different branches of science.

1. *Geological Origin of Soil.*—The first thing to be done is to ascertain beyond a doubt whether the underlying rock is really the parent rock of the present soil.

2. *Local Orographical Conditions (Plain, Hillside, Depression, etc.).*—As we have already seen, in many cases the orographical conditions play a decisive rôle in the formation of soils, and unless we are familiar with these conditions we are likely to be led astray.

3. *Characteristic Vegetation and its Condition.*—The natural flora is particularly important; and even where it is lacking, or where it has been modified by human intervention, the wild vegetation—the weeds—in many cases is more characteristic for the soil than the cultivated plants. This does not mean, however, that cultivated plants are of no importance from the agronomical point of view. Indeed, the very oldest soil classifications will be found to include soil types denoted by the names of cultivated plants.

4. *Local Climatic and Meteorological Conditions.*—We should never rely exclusively on the regional climate; we have to ascertain whether the local meteorological records accurately reflect the average climate of the region, and to what extent the natural vegetation of the

soil corresponds with the observed climate. For these two factors are so completely interdependent that where there is any deviation, that deviation must be due to some peculiar cause requiring investigation.

5. *Soil Profiles and their Forms (Soil Morphology).*—The structure of a soil profile is one of the most important objects of a local soil survey, and requires detailed description and illustration.

The *soil profile* symbolises the face of the soil, reflecting its past and present condition. When a doctor makes a diagnosis, he first examines his patient's face and enquires about any past and present feelings or pains, etc. Soil profiles (and also farmers thoroughly familiar with the soil) in many cases betray to the pedologist very much concerning the soil's past and present condition that may be of use in directing further investigations. Since these characteristic morphological features may be observed on the exterior of the profiles, they are spoken of as *external* characteristics. Before discussing them, we must consider how to prepare and describe a soil profile with a view to studying its morphology.

A point of fundamental importance in preparing a soil profile is that the profile shall as far as possible embrace all the successive horizons in a manner permitting ready comparison between them. The first thing to decide is the limits of the profile. The upper end is fixed by nature (the surface of the soil); but it is not so simple a matter to demarcate the lower end. There are places where the depth of the profile is only a few centimetres, while in other places it may be several metres. *Theoretically, the soil profile reaches down to the lowest point affected by the soil-forming factors—to the point where these factors converted the parent rock into soil.* However, the effect exercised upon the parent rock by soil-forming factors often penetrates to depths inaccessible in practice (*e.g.*, the accumulation of certain easily soluble salts—$CaCO_3$, $CaSO_4$, etc.). In such cases we may confine our investigations to lesser depths where the reactions in the soil profile are so slight as not to induce any sensible morphological alterations in the parent rock.

FIG. 7.

In order to facilitate the work, we require as smooth and freshly cut a profile as possible—a profile observable both in the shade and in the sun. For this purpose a rectangular pit with a trench, as shown in Fig. 7, is usually dug.

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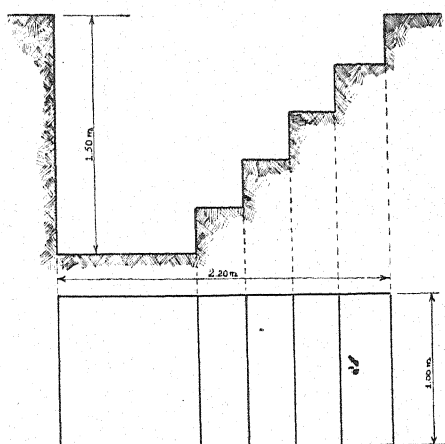
In view of the fact that the downward and upward movement of soil moisture and air exercises a far-reaching influence on soil transformations and penetrates to depths beneath the lower end of the soil, the level and composition of the ground water and the periodic fluctuations in the water table often supply valuable data about the character and the origin of the soil. In many cases it is necessary—or at any rate useful—to inquire into these matters.

The first thing we notice is that the face of the soil varies fairly considerably in colour. The changes of colour are not accidental, but are natural features of the different soil types. In the coloured plate at the end of the present work Profile No. 3 shows a forest soil, Profile No. 7 a black steppe soil, and Profile No. 9 a solonetz soil with columnar structure. The first thing noticeable about these three profiles is that none of them shows any sharply defined layers or horizons. In the forest soil and the solonetz soil profiles we are able to distinguish only three and in the steppe soil profile only two horizons. In the forest soil the upper humus cover, which is not a fully developed soil, merely covering the upper, greyish *podsolic* horizon, is not reckoned as a horizon; if we do include it in the upper horizon, we divide the latter into two sub-horizons. Most pedologists do not in general regard the forest humus cover as a real horizon. For in fully developed podsolic forest soils there are really three horizons only—viz., the upper *eluvial* or *A horizon*, the middle accumulation or *illuvial B horizon* and the parent rock or *C horizon*. We find three horizons of a somewhat similar character in the solonetz profile; only the colour, shading and structure of the several horizons are different. The upper, greyish A horizon of the forest soil does indeed tally with that of the solonetz soil; the latter, however, is usually laminated or crusty in structure, whereas the podsolic horizon of the forest soil is generally uniform—loose, sandy or dust-like, practically structureless. The A horizon of forest soils may often be divided into two sub-horizons, A_1 and A_2; of these the upper (A_1) is of a rather darkish colour produced by the humus substances percolating out of the humus cover (sometimes called A_0), the other sub-horizon (A_2) being formed only at a lower level, this being the podsolic horizon which is almost white in colour. Below the A_2 is the B, or accumulation, horizon, which may also in many cases be divided into two or three sub-horizons. The B_1 horizon is brownish black, containing precipitated humus materials. The B_2 horizon is rusty brown, containing hydrated ferric oxide, which often cements the soil aggregates to form very peculiar structures of a lumpy character or impermeable " *hardpans*." These soil formations cemented by ferric oxide, which the German scientists call " Ortstein " (*iron pan*), are found mostly in sandy soils of coniferous forests. The iron horizon often contains calcium carbonate too, though there are cases in which a calcareous accumulation horizon (B_3) occurs under the iron horizon and above the parent rock (C horizon).

In the columnar alkali soil, too, the B horizon is the accumulation

horizon, the upper sub-horizon (B_1) of which looks as if it was formed of columns. The lower part of the B horizon is polygonal in structure; it may be called B_2: it is followed by B_3—the horizon of calcareous concretions—and then by C_1. At the bottom of a heavy clay alkali soil we usually find a layer of grey or yellowish impermeable lacustrine clay (in some cases only at a depth of 5-6 metres) which may be called the D horizon. It must, however, be noted that strictly speaking this is not a part of the true profile, for its parent material was not that from which the soil has been formed.

Finally, in the black steppe soil profile there is no B or accumulation horizon, while the upper horizon (A) is not an eluviated horizon, but in view of its organic substances rather an accumulation horizon. The upper horizon is therefore the darkest, the soil becoming lighter as we proceed downwards, though here and there we may find dark spots marking the original burrows and runs of rodents living in the soil which have been filled in with black soil brought down or washed down from the upper horizon. It may also happen that an animal living in the soil pushes up lighter earth, the result being that we find light spots in the dark horizon. According to GLINKA, virgin black steppe soil consists of pea-shaped crumbs, due to the saturation of the humus-rich soil with calcium.

It is true, indeed, that terms like " pea-shaped," " nutty," " polygonal," " columnar," " laminated," etc., are very indefinite, their interpretation being purely subjective; they are nevertheless commonly used, and for the present we must for lack of better ones be content to use them. Recently some of the Russian soil scientists have endeavoured to denote structural values and varieties by numbers. TIULIN, for instance, suggests a method of determining the structure of soils similar to mechanical analysis, whereby—in addition to the mechanical composition of the soil—he determines the stable aggregates which cannot be dispersed by water.*

6. *Humidity and Water Régime of Soil Profiles.*—In profile studies the absolute water content is not so important as the relative wetness or dryness (ascertainable by touch) of the horizons, and the level of the ground water. Special account should be taken of the latter and of other local hydrographical conditions. For similar reasons we must note down all features observable in the profile which may cause the horizons to be permeable or impermeable.

7. *Local Chemical, Physical—and Possibly Biological—Tests.*— We are only concerned with these tests in so far as they contribute to the general characterisation of the profile and may serve as a basis for further more exhaustive chemical, physical or biological researches. The following are some of the tests usually made:

(a) The *detection of the vertical distribution of calcium carbonate* by dropping *dilute hydrochloric acid* on the whole profile.

* See TIULIN, A. TH.: Investigations of Perm Agric. Exp. Stat., Div. of Agric. Chemistry, No. 2, 1928.

(*b*) The *testing of soil reaction* in the different horizons.

(*c*) A thorough investigation of any *concretions* found in the profile, and their composition ($CaCO_3$, gypsum, ferric oxides, etc.).

(*d*) The testing of the *solubility of the humus* in water, dilute ammonia or other solvent. The mobility of humus substances is characteristic alike of forest and of alkali soils. The saturated humus of steppe soils and rendzinas is insoluble unless previously liberated by some acid.

(*e*) The detection of the presence of *ferrous iron*, which shows where reduction processes predominate.

(*f*) The examination (in alkali soils) of the kind, quantity and vertical distribution of *water soluble salts*.

(*g*) Careful *physical tests*, which are of the utmost importance. There are several physical peculiarities which can be detected by observation and are of great use for characterising a profile.

(*h*) *Biological tests*, which do not involve any very accurate or detailed researches. Very important, for instance, is the finding of the remains, the bones or the subterranean dwelling of some rodent (*crotovine*). Any horizon in which we find fresh-water snails must undoubtedly be of lacustrine or of marshy origin, even where forests or steppes have developed later on. As we have seen, earthworms are found in well aerated forest soils as well as in black steppe soils, and denote a state of good aeration, which leads us to expect aerobic bacteria also. On the other hand, where the humus cover of a forest soil is interwoven with mould mycelia and signs of peat formation are in evidence, we must assume the presence of an anaerobic microflora.

The conclusions to be drawn from these phenomena observed on the spot enable us to form a provisional opinion on the soil type. We can then ascertain which details require to be subjected to a more thorough chemical, physical and biological investigation.

<div align="center">CHAPTER XI</div>

CHEMICAL PROPERTIES OF SOILS AND THEIR CHARACTERISATION

THE chemical investigation of soils may be effected in many different ways. In the present chapter we shall, however, examine only those chemical properties which are essential for understanding and characterising a soil. Admittedly, the chemical composition of a soil at any time merely reflects its momentary condition, but where we find a basis for comparison with the original—or at least an earlier—stage of development, the difference between the two data enables us to obtain some idea of the alterations which have taken place, and to ascertain the direction and nature of the dynamic phenomena prevailing

at present in the soil. The basis for a comparison is supplied by the parent rock from which the soil has been formed. But even if we are unable to reach the parent material, a comparison of the composition of the several horizons will enable us to form an idea of the dynamic state of the soil.

In the section dealing with soil genetics we have already come to know a few characteristic phenomena (formation of humus, alkalisation, podsolisation, etc.) taking part in soil formation. These phenomena mainly comprise transformations of the parent rock (weathering, leaching out, accumulation, absorption, etc.), and the chemical changes are in many cases revealed by the external features of the soil profile. These external features are therefore closely connected with the internal chemical changes, what is practically a cross-section of the latter being provided by the chemical composition of the soil horizons.

It would naturally be a mistake to conclude that only the chemical features are of use for characterising the dynamic condition of the soil. In many cases the biological condition of the soil is just as important, but even then it is the chemical changes accompanying the biological phenomena that give the soil its permanent character. An acquaintance with the chemical character of a soil enables us also to draw conclusions about its biological condition. Thus, in acid soils poor in calcium the *azotobacter* or nitrifying bacterium is less active. In the case of acid soils we may therefore conclude from the chemical character itself that the fixing of free nitrogen from the air by bacteria must be only very slight and that the formation of nitrate practically ceases. Now, since soils of this kind are usually avoided by *papilionaceæ* (with the possible exception of lupines), the nitrogen-fixing effect of these plants is also lacking. There being no nitrification in these soils, the nitrogen found in them is not so readily available as a plant nutrient as it is in good humus, neutral or slightly alkaline soils, for which reason acid soils are particularly responsive to nitrates. This single example shows us that a relatively slight—though characteristic —element of the chemical condition of the soil suffices to enable us to presume the existence of many important biological phenomena of value not only theoretically, but also from a practical point of view.

A knowledge of the chemical condition often enables us to guess also the physical behaviour of the soil. For instance, where the absorption complex of the soil contains a considerable proportion of exchangeable sodium, but the soil itself contains few free sodium salts and no $CaCO_3$, we may presume a high degree of dispersion. When wet, a soil of this kind swells, while when it dries up it shrinks considerably, forming large cracks. Its aggregates have a characteristic structure and are often as hard as iron. These peculiarities are all found in the so-called leached alkali soils.

The examples I have given above were offered to show the close connection between the chemical condition of the soil on the one hand and its physical and biological behaviour on the other, it being possible

to draw conclusions from one property as to what the other properties must be. While it is true, therefore, that *strictly speaking the chemical composition reflects merely the present condition, it nevertheless bears so lasting an impression of the past and has latent in it such unmistakable indications of the future that we can understand the whole dynamic character of a soil from what the soil itself has to tell us.*

In the following sections I shall not deal with soil-testing methods from an analytical or practical point of view, but shall confine myself to explaining what can or may be deduced from the results of analyses and show how they may ultimately be utilised for characterising soils.

The chemical characteristics of soils may conveniently be divided into several groups. I shall therefore treat of the chemical description of soils under the following heads:

1. The mineral-chemical composition of soils.
2. The chemical characteristics of soil organic matter.
3. Characteristics of the absorption complex of the soil.
4. Colloidal explanation of adsorption phenomena and coagulation in the soil.
5. Characteristics of the water extract of the soil.

1. Mineral-Chemical Composition of Soils.

As regards chemical composition, we must distinguish between the inorganic and the organic part of the soil. The bulk of the former is usually of mineral origin; and we are therefore justified in speaking of the mineral-chemical composition of soils, even if we do not inquire into the true mineralogical composition.

At first sight it would appear that the mineralogical analysis of soils should be of the utmost importance in estimating their mineral-chemical composition. However, a study of the scientific literature available on the subject makes us realise that we know the mineralogical composition of comparatively few soils. Why then has the mineralogical analysis of soils been so neglected? What are the prospects of mineralogical analyses of soils becoming more common? In my opinion, since soil-forming processes usually begin when the parent rock splits up into its constituent elements not only physically but chemically too, the only information obtainable from all residues of the original minerals will relate to the past—the origin—of the soil and to the raw material in reserve for use in the future. For that reason purely mineralogical analyses can usually be employed only to a restricted extent for characterising the various soil types. The case is quite different with the recent investigations of the colloidal fractions, which cannot be regarded as original minerals, but as the results of chemical reactions occurring during the weathering process. From some of the investigations we may conclude also that the same

secondary minerals contribute actively to the reactive capacity of the colloidal fractions.

Therefore, though the mineralogical composition of the soil is not yet regarded as suitable for using independently for the purpose of soil characterisation, it nevertheless often serves to supply very valuable data to supplement the chemical and even the mechanical analysis. In many cases the proportion of easily to less easily decomposable minerals enables us to infer the degree of weathering undergone, particularly if we compare the mineralogical composition of the several horizons with the parent rock.

In doubtful cases a comparison of the mineralogical composition of the several horizons will also help us to ascertain whether the soil was really formed out of the underlying rock, or whether it has been formed from deposits of a parent material originating from some other place. By this method BALLENEGGER proved that the red soil (*nyirok* soil) of Mád, Hungary, was really formed from the rhyolite found beneath it—the formation dating probably from an earlier geological age in which these rhyolite hill-cones formed the shores of the inland sea covering the territory now known as the Hungarian Lowlands, which must have had a climate almost identical with that of the Adriatic and Mediterranean Seas today.*

In the dynamic system of the soil the original minerals pass through transformations of a more or less chemical character. The minerals break up into their elements or into residual compounds which then either form new compounds or complexes respectively (*e.g.*, $CaCO_3$, $CaSO_4$ or zeolite complexes), or the decomposition products remain intact in the soil (*e.g.*, Al_2O_3, Fe_2O_3 or SiO_2 gels). Subsequently these compounds either remain in the soil as they are or become more or less leached out or accumulate in one or other of the horizons. We have already seen how important these phenomena of soil formation are for the development of the several soil types. The only information we can obtain about these phenomena is given not by mineralogical but by chemical analysis. What is essential for soil determination is to ascertain not the residual fresh minerals, but rather *the composition of the weathered mineral part not determinable mineralogically*.

In the mineral part of the soil we may theoretically distinguish three groups—viz., (1) unweathered débris of original minerals, mostly crystalline in structure; (2) amorphous weathering products (of coarse or colloidal dispersion) which are not definable mineralogically, while some of them may display the phenomena of base-absorption; (3) crystalline compounds or such compounds as are easily definable chemically—*e.g.*, the various salts and oxides or, as shown by recent research, crystalline secondary minerals.

A mineralogical analysis of the soil naturally affords information only about the first group or at most about certain crystalline weathering products formed in the soil. A total chemical analysis by fusion.

* See BALLENEGGER, R.: Földt. Köz., Vol. XLVII. (1917), p. 20.

on the other hand, enables us to determine all three groups together, though even then we cannot obtain indisputable data regarding the degree of weathering or the leaching process. Fusion-analyses sometimes give information enabling us to estimate the absolute losses, but this information is usually restricted and often misleading, as may be seen from Helbig's data in Table XIX.*

TABLE XIX

	Total Analysis by Fusion.			Analysis of the HCl Extract.		
	Podsol Horizon.	Iron-Ore Horizon.	Parent Rock.	Podsol Horizon.	Iron-Ore Horizon.	Parent Rock.
SiO_2 per cent.	81·46	62·83	69·64	0·0969	2·2076	0·1178
Al_2O_3 ,,	10·22	18·56	15·24⎫	1·5399	12·2624⎫	8·1492
Fe_2O_3 ,,	1·38	4·80	2·33⎭		1·5688⎭	
MnO ,,	0·11	4·14	1·12	0·1055	0·5634	0·2363
CaO ,,	0·17	0·78	0·97	0·1167	0·1819	0·1973
MgO ,,	0·57	0·63	0·69	0·0624	0·3380	0·1421
K_2O ,,	3·90	4·48	5·20	0·0935	0·2062	0·2188
Na_2O ,,	3·64	4·63	5·47	0·1223	0 1591	0·0544
P_2O_5 ,,	0·29	0·89	0·58	0·0282	0·1268	0·0920
SO_3 ,,	—	—	—	0·0491	0·2552	0·0522

The point particularly worth noting in the above table is the changes in the quantities of SiO_2 and sesquioxides. From the total analysis by fusion we see that the SiO_2 considerably increased in the podsol horizon, while the soluble SiO_2 (extracted by HCl) was leached out. The apparent contradiction shown here may be explained by the circumstance that the quartz dissolved by fusion is insoluble in nature and consequently actually increases relative to the other, soluble elements. It would be a mistake, however, to conclude that no SiO_2 migrates during podsolisation, for the data of the hydrochloric extract prove that the amount of soluble SiO_2 in the iron-ore horizon is 22 times as great as in the podsol horizon. We shall have no difficulty in understanding this when we study the migration of sesquioxides as shown by the hydrochloric extract. These, too, increase in the iron-ore horizon; the explanation being that the Al_2O_3, Fe_2O_3 and SiO_2 gels originating from the weathering of the silicates—either independently or to some extent interdependently—have followed the direction of leaching and have accumulated by precipitation in the iron-ore horizon.

In the section dealing with the different types of soil formation we explained the special use of hydrochloric-acid extracts. All I intend to do here is to summarise the general principles used to interpret the results obtained from them.

* See GLINKA, K.: *op. cit.*, p. 80.

From HILGARD's original data in column 1, Table XX., we see the characteristic difference in the average composition of the hydrochloric extracts of humid and arid soils respectively. In humid soils, for instance, the insoluble residue is 14 per cent. more, due to the more energetic leaching in comparison with arid climates. As a consequence the soluble part, consisting of aluminium silicates decomposable by

<div align="center">TABLE XX</div>

<div align="center">AVERAGE COMPOSITION OF HUMID SOILS</div>

	Per Cent.		Per Cent.	Gramme-Equivalents.	Sum of + and - Equivalents.	Equivalent Per Cent.
Na_2O ..	0·091	Na^I ..	0·067	0·00291		0·82
K_2O	0·216	K^I ..	0·178	0·00456		1·28
CaO ..	0·108	Ca^{II} ..	0·077	0·00386		1·08
MgO ..	0·225	Mg^{II} ..	0·131	0·01094	0·35573	3·07 |100
Fe_2O_3 ..	3·131	Fe^{III} ..	2·192	0·07843		22·05
Mn_3O_4 ..	0·133	Mn^{III} ..	0·096	0·00349		0·98
Al_2O_3 ..	4·296	Al^{III} ..	2·289	0·25154		70·72
SO_3 ..	0·052	SO_4^{II} ..	0·062	0·00129		0·36
P_2O_5 ..	0·113	PO_4^{III} ..	0·152	0·00481		1·35
SiO_2 ..	4·212	SiO_4^{IV} ..	6·456	0·28117	0·35573	79·05 |100
Loss on ignition	3·644	O^{II} ..	0·546	0·06846		19·24
Insoluble residue	84·031	Loss on ignition	3·664			
		Insoluble residue	84·031			
Total 100·252			99·951			

<div align="center">AVERAGE COMPOSITION OF ARID SOILS</div>

	Per Cent.		Per Cent.	Gramme-Equivalents.	Sum of + and - Equivalents.	Equivalent Per Cent.
Na_2O ..	0·264	Na^I ..	0·196	0·00852		1·19
K_2O ..	0·729	K^I ..	0·605	0·01550		2·17
CaO ..	1·362	Ca^{II} ..	0·973	0·04877		6·82
MgO ..	1·411	Mg^{II} ..	0·846	0·07068	0·71517	9·88 |100
Fe_2O_3 ..	5·752	Fe^{III} ..	3·027	0·10830		15·14
Mn_3O_4 ..	0·059	Mn^{III} ..	0·042	0·00150		0·21
Al_2O_3 ..	7·888	Al^{III} ..	4·203	0·46187		64·59
SO_3 ..	0·041	SO_4^{II} ..	0·049	0·00102		0·14
P_2O_5 ..	0·117	PO_4^{III} ..	0·156	0·00493		0·69
CO_2 ..	0·316	CO_3^{II} ..	1·792	0·05989		8·37
SiO_2 ..	7·266	SiO_4^{IV} ..	11·136	0·48504	0·71517	67·83 |100
Loss on ignition	4·945	O_2^{II} ..	1·311	0·16429		22·97
Insoluble residue	70·565	Loss on ignition	4·945			
		Insoluble residue	70·565			
Total 101·715			99·846			

acids, and of alkaline earth carbonates, accumulates in arid soils quantities of soluble SiO_2 and Al_2O_3 averaging nearly twice as much as in humid soils. There are no carbonates at all in humid soils. It should be noted that HILGARD deliberately omitted from both groups soils formed on calcareous or dolomite rocks, lest the extreme composition of the parent rock should mask the pedogenic effect of the climate. When we examine more closely the chemical composition of the fraction soluble in hydrochloric acid we find also that the sum of the gramme—equivalents of the positive constituents in arid soils is roughly twice as great as in humid soils. Now, from the last column we see that in arid soils the sum of the equivalent percentage of the trivalent cations (Al, Fe and Mn) is barely 80 per cent., whereas in humid soils it exceeds 90 per cent., showing that as a consequence of the more intensive leaching of the univalent and bivalent cations, the trivalent cations, which are less mobile, are present in larger quantities.*

VAN BEMMELEN, when dealing with the colloid materials found in soils, and with their absorption phenomena, divided the soil silicates into two main groups—*weathered silicates* and *unweathered silicates*. He found that cold concentrated sulphuric acid decomposed and dissolved all products of weathered silicates, the residue consisting solely of unweathered silicates. Hot sulphuric acid, on the contrary, exercised a powerful decomposing effect on the original silicates also.

VAN BEMMELEN divided the weathered silicate complex into two parts, the A and B complexes. The A complex comprises all the substances taking part in the absorption phenomena of the soil. These, he found, all became soluble after two hours' boiling with concentrated hydrochloric acid. The residue, which is soluble in concentrated sulphuric acid, is not capable of absorption and in its composition resembles kaolin. In short, we may as a result of VAN BEMMELEN's researches divide the soil into three silicate complexes: (1) the absorption silicate complex (A complex); (2) the kaolin-like silicate complex (B complex); (3) the unweathered silicate complex, the latter being determinable by fusion of the insoluble residue of the sulphuric acid extraction.

VAN BEMMELEN, it should be noted, emphasised that the constituents dissolved by hydrochloric or sulphuric acid cannot be regarded as single compounds or even as mixtures of well-defined chemical compounds (silicates). Many workers—especially STREMME—have declared emphatically that these complexes—and particularly the A

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* For details see SIGMOND, ALEXIUS A. J. DE: "Introduction of a New Terminology in Indicating the Chemical Composition of Minerals and Soils" (Intern. Mitt. f. Bodenkunde, Vol. II., 1912, Nos. 2-3).

See also HILGARD, E. W.: "A Report on the Relation of Soil to Climate" (U.S. Weather Bur. Bull., 3, 1892; "Über den Einfluss des Klimas auf die Bildung und Zusammensetzung des Bodens" (Heidelberg, 1893); Ann. Sci. Agron., Vol. II. (1892), pp. 92 and 395; "The Relation of Soils to Climate" (Calif. Exp. Stat. Rept., 1892-93 and 1894).

complex—are irregular mixtures of SiO_2 and Al_2O_3 gels.* GANS (GANSSEN), on the other hand, regarded the hydrochloric acid extract as being colloidal zeolites, presuming that he could reconstruct their chemical formulæ from the composition of the hydrochloric acid extract.† When he started his work, he did actually reconstruct the silicate complex from the data of the hydrochloric acid extract prepared by HILGARD's method, making far-reaching deductions therefrom. The fundamental idea underlying this reconstruction is as follows.

The first thing he did was to convert the percentage composition of the hydrochloric acid extract by means of the dualistic method usual in mineralogy into oxide and acid-anhydride molecules. From the sum of the molecules of bases he then deducted a proportion corresponding to the valency of the acid anhydrides (except silicic acid anhydride) in order to eliminate the salts accompanying the silicate complex or the equivalent bases of the latter. Next he calculated the number of SiO_2 molecules and of the remaining base molecules relative to the number of Al_2O_3 molecules. He found that in most soils to every molecule of Al_2O_3 there were three or more molecules of SiO_2, while the molecular ratio of bases to Al_2O_3 was about 1. Since he had previously found that both in natural chabasite-like and in artificial zeolites the ratio $SiO_2 : Al_2O_3 : RO$ was roughly $3 : 1 : 1$, only the SiO_2 occasionally exceeding this proportion,‡ he adopted this formula as a basis in classifying soils. In his opinion soils in which the silicate complex corresponds to the above formula are neutral soils saturated with bases; while those in which the proportion of RO is less than 1 are unsaturated—*i.e.*, acid—soils, and those in which the proportion of RO is greater are alkaline soils.

At the time the conclusions arrived at by GANSSEN awoke universal interest and were made the centre of discussion and inquiry. The importance of the question was stressed in particular by RAMANN.§ For RAMANN regarded GANSSEN's researches as having proved that there are two groups of hydrated aluminium silicates occurring in soils. A peculiarity of the first group is that it very rapidly exchanges its bases for the bases of other solutions, whereas the bases of the second group are not easily exchangeable, the process of exchange here being a slow one. It is therefore possible with the help of concentrated salt solutions to separate the bases absorbed in the soil into two groups— viz., the group of rapidly exchangeable bases and the group of bases which can be exchanged either only slowly or not at all. For this purpose RAMANN suggested a method of investigation employed as the

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* See STREMME, H.: Monatsber. Dtsch. Geol. Ges., Vol. LXII. (1910),p. 122, and Centrbl. Mineral. Geol., 1914, p. 80.

† See GANS, R.: Int. Mitt. Bodk., Vol. III. (1913), p. 529.

‡ See GANS (GANSSEN), R.: Jahrb. Kgl. Preuss. Geolog. Landesnstalt, Vol. XXVI. (1905), p. 119, and Vol. XXVII. (1906), p. 63.

§ See Int. Mitt. Bodk., Vol. V. (1915), p. 41.

basis of many similar researches in the years that followed.*   There
is therefore no disputing the value of GANSSEN's services in this field.
The conclusions respecting the molecular reconstruction of the silicate
complex drawn by him and referred to above have not proved correct
in every respect.

In the first place it has been shown that the molecular reconstruction
depends considerably on the method of preparing the hydrochloric acid
extract.   Experiments made by us with soils from Hatvan showed
(Table XXI.) that the soil appeared as alkaline, acid or neutral respec-
tively according to the method employed.†

TABLE XXI

Method Used.	SiO₂ Molecules.	Al₂O₃ Molecules.	RO Molecules.	According to Ganssen.
Hilgard's	3·09	1	1·23	Alkaline
Official American	4·25	1	0·80	Acid
One hour boiling	4·20	1	1·31	Alkaline
Official Russian	4·05	1	1·08	Neutral

This fact has recently been admitted by GANSSEN himself, who was
not prepared to accept the method suggested by VAN BEMMELEN and
HISSINK because in his opinion it decomposes at least 8 per cent. of
the original silicates and thereby leads to false conclusions.   According
to UTESCHER and GANSSEN the method of the Prussian Institute of
Geology—which differs only very slightly from that of VAN BEMMELEN
and HISSINK—does not seriously attack the unaltered silicates, so
that from the molecular ratios we can draw very far-reaching conclusions
about the reaction condition of the soil, its abundance in nutrients and
other chemical properties.‡   Not only does this recent method differ
materially from HILGARD's and the official American methods, but also
from GANSSEN's original method.   GANSSEN at first subjected the soil
for 24 hours to the reaction of 20 per cent. cold hydrochloric acid;
his latest method is to boil the soil for 1 hour in an open vessel with
20 per cent. hydrochloric acid.§

Although I have not had an opportunity to check the official Prussian
method, it should be noted that UTESCHER and GANSSEN have so far
failed to offer any experimental data to prove that the new method

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* It should be noted that the publications of GEDROIZ, which appeared in
Russian in 1912, provided with a summary in German and containing the results
of similar experiments, were still unknown in international literature.
   † See SIGMOND, A. A. J. VON: Int. Mitt. Bodk., Vol. V. (1915), p. 197.
   ‡ See UTESCHER, K.: Ztschr. Pflanz. Düng. Bodk. A., Vol. XI. (1928), p. 275.
   § See GANS (GANSSEN), R.: Jb. Kgl. Preuss. Geol. Landesanst., Vol. XXVI.
(1905), p. 207, and UTESCHER, K.: Ztschr. Pflanz. Düng. Bodk. A., Vol. II.
(1923), p. 370.

really scarcely decomposes the silicates present in the soil, even if they have proved that the results obtained by the two processes are divergent.*

My own experiments have, however, shown that the quantity of bases dissolved in the hydrochloric extract prepared according to the method of van Bemmelen and Hissink is always materially in excess of that of all the exchangeable bases combined. This may be seen from the data given in Table XXII.

TABLE XXII

PERCENTAGE OF EXCHANGEABLE CATIONS IN THE TOTAL AMOUNT SOLUBLE IN HCl

1. *Slightly Podsolised Forest Soil, Hüvösvölgy, Hungary.*

Soil Horizon.			Ca	Mg	K	Na
A	..	..	21·75	15·77	18·18	5·08
B_1	..	..	10·20	12·95	16·90	9·38
B_2	..	..	17·85	5·69	21·44	9·65
C	..	..	25·00	5·24	16·20	14·85

2. *Dark Brown Steppe Soil, Csorvás, Hungary.*

A	..	..	26·3	1·44	19·6	4·7
B_1	..	..	27·5	2·35	1·0	3·5
B_2	..	..	36·4	0·56	5·1	74·5

3. *Black Steppe Soil, Pusztakamarás Transilvany.*

A	..	..	72·3	2·8	4·72	6·1
B	..	..	69·0	2·45	5·3	9·0
C	..	..	83·0	1·47	4·82	14·4

4. *Leached Alkali Soil, Hostolágy, Hungary.*

A	..	..	27·55	40·7	15·6	26·55
B_1	..	..	34·20	17·9	10·8	19·90
B_2	..	..	26·50	21·9	7·55	24·80
B_3	..	..	39·40	11·5	6·7	32·3
C_1	..	..	36·70	12·65	31·6	58·4
C_2	..	..	32·78	79·0	45·3	48·1
C_3	..	..	44·69	65·5	43·6	64·8
D	..	..	39·45	45·9	33·1	44·2

Now, though according to GANSSEN's theory the bases of the zeolite complex are rapidly and completely exchangeable, the above data prove that the bases dissolved by hydrochloric acid are not identical with the exchangeable bases. According to GEDROIZ results can be obtained by the use of $0·05N$ HCl similar to those obtained by exchange with neutral salt solutions. Now it is inconceivable that boiling 20 per cent. HCl should react only to the same degree as the above

* See SIGMOND, A. A. J. von: "Bemerkungen zur Frage der Zubereitung des Salzsäureauszuges" (Verh. II. Komm. Int. Bodkl. Ges. A., Budapest, 1929, p. 13).

dilute HCl. For these reasons the Second International Soil Science Commission rejected UTESCHER'S proposal and accepted as official the method suggested by VAN BEMMELEN and HISSINK.* But we cannot regard the hydrochloric extract as enabling us to reconstruct the chemical composition of the zeolite complex of the soil. For hydrochloric acid decomposes not only the zeolite complex but also the fresh minerals and less decomposable silicates. A more exact chemical characterisation of the hydrochloric acid extract is to express the constituents by their equivalents. In that case there is no need of arbitrary assumptions—except that we regard the combined silicic acid as SiO_4, this being the form in which silicic acid is most likely to be found in the weathered silicates and silicate complexes.

The pedological importance of the B complex, decomposable by sulphuric acid, is not yet quite clear; and for that reason I shall confine myself to explaining the several constituents of the A complex or rather the pedological interpretation of the hydrochloric extract.

It should be noted that the silicic acid liberated from silicates by the action of the hydrochloric acid, although insoluble in that acid, nevertheless forms an integral part of the hydrochloric extract. This silicic acid is therefore dissolved in sodium hydroxide and added to the SiO_2 soluble in hydrochloric acid. Unless this is done, the interpretation of the hydrochloric extract will be not only deficient but actually misleading; for the insoluble residue would appear more, and the soluble SiO_2 less, than it really is.

I shall now treat separately the several constituents of the hydrochloric extract.

1. *Insoluble Residue.*—This is really the inactive and most resistant part of the soil; it consists chiefly of quartz combined with a certain quantity of intact silicates and kaolin-like weathering residue resistant to the action of hydrochloric acid. The amount of such residue varies very considerably in different soils and soil horizons. In sandy soils—particularly where the sand consists of leached quartz—its proportion is far in excess of 90 per cent.; and in the leached soils of humid climates in general the proportion averages 80-85 per cent. In dry climates, in soils which are not sandy, the proportion of this residue declines even to less than 50-60 per cent.; indeed, in calcareous soil horizons we repeatedly find it as low as 20 per cent. Consequently, those soils which contain a relatively large proportion (exceeding 80 per cent.) of insoluble residue are usually either sandy or more or less leached soils.

2. *Soluble SiO_2.*—This term comprises the SiO_2 soluble in HCl and dilute alkalies; for the hydrochloric extract usually contains barely $0·1-0·2$ per cent., whereas combined with that found in the dilute alkaline solution it often amounts to 10-15 per cent. The large quantity of soluble SiO_2 points to silicate weathering on a large scale. It should,

* See Proceedings of Second Commission of International Society of Soil Science, Vol. B, Budapest, 1929, p. 18.

however, be noted that the hydrochloric acid partly decomposes the unweathered silicates, from which part of the soluble silicic acid originates. There can be no doubt that the hydrochloric acid first decomposes the A silicate complex which is the residue of the silicate weathering. Therefore, though perhaps GANSSEN's statement that we can reconstruct the weathered silicate complex from the hydrochloric extract is rather optimistic, it is nevertheless indubitable that the bulk of the soluble silicic acid originates from the weathered silicate complex. It is equally indubitable that the SiO_2 dissolved in dilute alkali may occur partly in a free state as silicic acid gel, though this is so only when the decomposition of the silicates is active. This detail can also be determined by subjecting the original soil sample to the action of dilute alkalies. The SiO_2 dissolved by this direct action may be assumed to occur in a free state, and is not part of the zeolitic silicate complex.

3. Al_2O_3.—Aluminium oxide is at least as important for the characterisation of soils as the soluble silica with which it is usually associated; for the bulk of the latter also originates from weathered aluminium silicates and is a typical constituent of the zeolite complex. Hence, in soils in which there is a relatively large proportion of Al_2O_3 soluble in hydrochloric acid, the zeolite complex also usually has a high value. It is clear that when the hydrochloric acid dissolves bases in excess of the exchangeable bases, the quantity of dissolved Al_2O_3 and SiO_2 must also be far in excess of that corresponding to the absorption complex (T). We find, however, that any decrease or increase of the T-value is sometimes accompanied by a corresponding decrease or increase in soluble SiO_2 and Al_2O_3. In this connection we must not forget either that the Al_2O_3 may also occur free, as gels, soluble in dilute alkalies. To determine the combined Al_2O_3, we must deduct the free from the total Al_2O_3 dissolved in hydrochloric acid. Particular importance attaches to the free Al_2O_3 and SiO_2 in those soils in which the silicates decompose into their constituent elements, as, for example, in podsols, brown forest soils, red earth (*terra rossa*) and laterites.

4. Fe_2O_3.—This term really includes not only ferric but also ferrous oxide compounds dissolved by hydrochloric acid. It would be useful if we could determine separately the ferrous compounds originally existing in the soil, for the amount might serve as a kind of measure to indicate the reduction processes prevailing in the soil, but at present we do not know any suitable method. It must not be forgotten that ferrous compounds are easily oxidised in contact with air, the result being that by the time the soil sample packed in the usual way reaches the laboratory some of the ferrous compounds have become ferric compounds. We have to be content, therefore, with trying to detect ferrous compounds qualitatively when the soil sample is taken. By so doing we avoid being misled in cases in which the original soil would have shown a positive ferrous reaction. Our present knowledge of the rôle played by ferrous iron is deficient, due to our not having at our

disposal adequate experimental data. The iron in the soil is partly of mineral and partly of vegetable origin, consequently the Fe_2O_3 detected by analysis has to be subjected to criteria quite different from those applied to the Al_2O_3. Whereas the latter originates almost exclusively from aluminium silicates, or rather from their weathering products, thus enabling quantitative deductions to be made regarding the changes undergone during their weathering and leaching—the quantitative change of the Fe_2O_3 enables us to draw conclusions not only about the circumstances governing the weathering and leaching of the silicates, but also about changes undergone by the soil organic matter. It is indubitable that changes in the Al_2O_3 and the Fe_2O_3 are very frequently (though not always) parallel. Even though these two kindred constituents may migrate similarly in the horizons, we must never forget that the migration of the iron to a great extent keeps pace with that of the humus. This fact is evidenced best by the iron concretions which are common in certain soils and usually contain a considerable quantity of organic matter in addition to the iron. In these concretions the Al_2O_3 content is usually extremely low, showing that the organic matter is often combined with the iron—and possibly also with manganese, which is found in many cases in considerable quantities.

Recent investigations of the conditions governing the formation of red earths have produced evidence that in certain circumstances the Fe_2O_3 gel may combine with the SiO_2 gel in the same way as the Al_2O_3 gel, this being the probable origin of the characteristic red colour of *terra-rossa* soils.

We see, therefore, that the quantitative changes of the Fe_2O_3 allow conclusions to be drawn which are often extremely valuable and many-sided, and do not always correspond to the phenomena relating to Al_2O_3.

5. Mn_3O_4.—The hydrochloric acid extract gives us even less information about the original forms in which manganese occurs than it does in the case of the iron; but manganese is usually a very insignificant and secondary constituent. In some iron concretions its quantity is considerable, but we know nothing respecting its real pedological importance.

6. TiO_2.—This is usually associated with SiO_2 and P_2O_5. At present we know nothing of its pedological importance.

7. CaO.—The calcium content of soils is of great importance for their chemical characterisation. HILGARD was the first to point out that in the soils of humid climates we find far less CaO than in soils formed in arid climates. Great importance attaches also to the calcium content of the parent rock; for we know that the soil formed from parent rocks containing $CaCO_3$ is often very different in type from that formed from parent rocks free from $CaCO_3$. Generally speaking, it is the quantity of calcium present that determines the chemical, physical and biological behaviour of soils. Of special importance are the

$CaCO_3$ and exchangeable calcium contents of the soil. The hydrochloric extract enables us to determine the total decomposed CaO, while the absorbed Ca is determined from the exchangeable cations (bases); the quantity of calcium combined with carbonic acid can be obtained by determining the latter. However, the hydrochloric acid extract itself shows whether the quantity of CaO in the soil is relatively large or small, determining also the rate of leaching. The more active the soil-leaching, the greater the depth to which the CaO is leached and the poorer the upper soil. Podsolic and degraded alkali soils are particularly poor in calcium.

8. *MgO.*—This is a soil constituent in many respects similar in its effect to calcium; nevertheless, its behaviour often differs from that of calcium: for there are soils in certain horizons of which MgO accumulates at the cost of CaO. We do not yet know the real causes or even the consequences of this phenomenon; it is a fact, however, that even in the presence of calcareous parent material it often happens that CaO is leached out of the upper horizons on a larger scale than MgO.

9. *K_2O.*—The quantity of potassium in the hydrochloric extract varies very considerably, though it is usually far less than 1 per cent., and therefore less than that of the bivalent bases. The potassium in the hydrochloric extract may originate from three different sources— from water-soluble potassium salts, from exchangeable potassium and from unaltered potassium silicates. The period of reaction by hydrochloric acid and other circumstances connected therewith greatly influence solution of the potassium silicates.

10. *Na_2O.*—This is the most mobile base in soil, and the quantity of Na_2O found in permeable soils of humid climates is usually infinitesimal, particularly in the upper horizons. Even in semi-arid soil types (such as tshernosems) it plays only a subordinate rôle in the upper horizons. In the lower horizons it accumulates more and more, and it often happens that in the C horizon of steppe soils the water-soluble and exchangeable Na is so abundant that the soil assumes a slightly alkaline character. This fact is shown even more strikingly by examining the absorption complex and by determining the ratio of the water-soluble sodium to the other bases. In the parent rocks the sodium is usually found in compounds which decompose more easily than the potassium compounds, and the hydrochloric extract of parent rocks is consequently often richer in Na_2O than in K_2O. It is only in the alkali soils, however, that we find the upper horizons containing any considerable quantity of sodium, due to the fact that leaching of the very mobile sodium has been impeded and the sodium has accumulated in the upper horizons.

11. *CO_2.*—If we leave out of account the soluble silicic acid, the most important acidic soil constituent is undoubtedly the carbonate-forming combined CO_2. As we shall see later, the bulk of the negative constituents found in the hydrochloric extract consists of the anions of silicic and carbonic acids, the amount of the rest being negligible.

The bulk of the CO_2 is combined with CaO, calcium carbonate being the most mobile soil constituent.

12. SO_3.—The SO_3 content of soils is barely 0·1-0·2 per cent., though in exceptional cases sulphates play a more important rôle. In certain types of alkali soils, for instance, sodium and magnesium sulphates are found in considerable quantities. The same is true also of soils which have originated from gypsum parent rocks. The results given by the hydrochloric extract of a Spanish soil profile of this kind are summarised in Table XXIII.*

TABLE XXIII

Horizon.	Ia. (Per Cent.).	Ib. (Per Cent.).	II. (Per Cent.).
Na_2O	0·17	0·21	0·04
K_2O	0·32	0·18	0·09
MgO	1·34	0·71	1·68
CaO	23·35	20·50	28·56
MnO	0·11	0·07	0·18
Fe_2O_3	3·70	1·75	0·16
Al_2O_3	1·03	0·76	0·34
SO_3	5·69	22·27	40·36
P_2O_5	0·12	0·07	—
CO_2	13·86	4·30	1·09
SiO_2	7·32	6·94	1·16
TiO_2	0·15	0·10	—
Insoluble residue	27·52	19·02	1·64
Loss on ignition	11·29	16·74	19·58
Water	4·43	7·29	5·35
Total	100·40	100·91	100·23

13. P_2O_5.—This soil constituent, in spite of its importance in plant nutrition, is quantitatively quite a subordinate one. It sometimes happens, however, that the hydrochloric extract shows that it is not always the surface horizon of soil that is richest in phosphoric acid. This is usually the case with acid soils, for the natural phosphates occurring in soil are more easily soluble in weak acids than in water. The fact that the surface horizon is nevertheless usually richest in phosphoric acid is due to the activity of plant roots, which transport phosphoric acid from the lower to the upper horizons. This effect is exercised particularly by the natural vegetation of steppe soils, which readily accumulates organic phosphoric acid in the upper horizons. This process is furthered by the calcium content of the steppe soils protecting the phosphoric acid set free from organic matter against leaching. In acid soils, on the contrary, the leaching may be extremely energetic, firstly, owing to the abundance of CO_2 and humic acids, which mobilise the phosphoric acid, and secondly owing to the deficiency of calcium.

* See VILLAR, E. H. DEL: " Les sols méditerranéens étudiés en Espagne " (Madrid, 1930).

14. *Cl.*—The chlorides present in soils naturally cannot be determined in hydrochloric extracts; indeed, the hydrochloric extract is unsuitable even for the determination of nitrate, the amount of NO_3 being usually so small that the quantity of soil used for the hydrochloric-acid extract is insufficient to make a determination possible. All chlorides and nitrates are easily soluble in water; therefore, and to determine the latter, we take more soil and use a water solution.

15. *Loss of Ignition and Moisture.*—It is better to exclude the moisture content from the hydrochloric extract data and calculate all figures to a soil dried at a temperature of 105° C. The loss on ignition consists of three parts: (1) organic matter; (2) chemically bound (combined) water; (3) in the case of carbonate soils, the CO_2 set free by ignition. The latter quantity must be deducted, only the difference being shown in the analysis. Consequently, the loss on ignition corresponds to the total amount of organic matter and combined water. It is usual in practice to deduct a certain aliquot of the loss on ignition as combined water, the aliquot depending upon the mechanical composition of the soil. According to NOVACKI,* this aliquot is:

For clayey soils .. .. $\frac{1}{2}$
For loamy soils .. .. $\frac{1}{3}$
For sandy loam, or loamy sand .. .. $\frac{1}{4}$

The object of all these corrections is to estimate the total amount of organic matter—or of what is commonly called humus. Undoubtedly, if we were able to determine exactly the amount of combined water not evaporable at 105° C, and deducted this amount from the loss on ignition, we should get much nearer the real amount of the organic matter than by the other analytical processes described below. The average values given above are not suitable for this purpose, as the quantity of water retained by the soil depends upon the physical condition of the soil colloids. Hence we could not deduce the amount of combined water even if we could determine exactly the total amount of colloidal material, and it is thus inadvisable to calculate the organic matter from the loss on ignition. On the contrary, it is better to reverse the process, and, after deducting the value for the total amount of organic matter calculated on the basis of the carbon content from the loss on ignition, to take the remainder as approximately corresponding to the amount of water retained at a temperature higher than 105° C.

Table XXIV. contains some relevant data obtained from Spanish soils tested by us.†

The first thing that strikes us when we examine these data is that there is no connection between the loss on ignition and the organic matter, not even within one and the same soil profile. As a consequence, whether the aliquot deducted from the loss on ignition

* See NOVACKI: " Praktische Bodenkunde " (1892), p. 108.
† See VILLAR, E. H. DEL: " Les sols méditerranéens étudiés en Espagne " (Madrid, 1930).

is $\frac{1}{2}$, $\frac{1}{3}$ or $\frac{1}{4}$, the remainder never corresponds exactly to the actual amount of organic matter. I am, indeed, of opinion that *we can never under any circumstances use the loss on ignition for estimating organic matter*.

However, we also find that the colloidal constituents occurring in the soil are not closely connected either individually or collectively with the combined water. Constituents of this kind are soluble SiO_2, Al_2O_3, Fe_2O_3, and the organic matter itself. VAN BEMMELEN's researches into changes in the water content of SiO_2, Al_2O_3 and Fe_2O_3 gels showed that these gels retain or lose water according to the conditions of temperature and vapour tension. It is therefore incorrect to call the water evaporable at a temperature exceeding 105° C. chemically bound or combined water. It is not the same as water of crystallisation of crystalline compounds, which in the case

<div align="center">TABLE XXIV</div>

Designation of the Soil.	Loss on Ignition (%).	Total Organic Matter (%).	Chem. H_2O (%).	Soluble SiO_2 (%).	Al_2O_3 (%).	Fe_2O_3 (%).	SO_3 (%).
St. 4. I.	10·19	5·91	4·28	7·39	1·37	3·05	0·16
,, II.	5·30	0·90	4·40	13·23	5·13	4·43	0·05
,, III.	3·91	0·35	2·56	15·85	8·46	1·67	0·16
,, IV.	4·31	0·09	4·22	3·84	1·20	0·99	0·06
Md. 52. S_4	8·12	2·09	6·03	5·52	0·74	1·11	0·06
,, I.	2·64	0·41	2·23	4·87	1·03	1·90	0·09
,, II.	3·61	0·29	3·32	14·35	7·24	1·56	0·09
,, III.	2·21	0·02	2·19	7·46	2·18	1·67	0·02
,, IV.	2·61	0·02	2·59	8·08	4·88	1·11	0·04
,, V.	3·25	—	3·25	9·69	4·24	0·61	0·04
Ct. 1. I.	12·38	7·98	4·40	5·96	3·24	2·14	0·22
,, II.	7·32	3·74	4·58	6·75	3·95	2·15	0·14
,, III.	6·10	3·03	3·07	7·29	3·23	3·02	0·06
,, IV.	1·06	—	1·06	2·81	1·17	0·97	0·14
Hc. 2. I.	5·94	2·55	3·39	11·19	7·87	3·02	0·14
,, II.	5·51	1·53	3·98	5·88	3·60	1·95	0·11
,, III.	3·60	0·51	3·09	3·70	2·16	1·85	0·14
,, IV.	0·10	—	0·10	0·75	0·26	1·12	0·15
Va. 3 I.	4·21	1·31	2·90	10·55	4·57	3·51	0·10
,, II.	4·95	1·12	3·83	12·72	6·86	2·05	0·14
,, III.	3·78	0·62	3·16	11·15	6·14	2·62	0·13
,, IV.	4·03	0·19	3·84	9·31	5·41	1·95	0·08
Md. 102. I$_A$.	11·29	3·86	7·43	7·32	1·03	3·70	5·69
,, I$_B$.	16·74	1·97	14·77	6·94	0·76	1·75	22·27
,, II.	19·58	0·73	18·85	1·16	0·34	0·16	40·36

of gypsum, for instance, amounts to 2 molecules of H_2O. In soils we can only exceptionally expect to find water of crystallisation. The last soil profile in Table XXIV. is a gypsum soil in which the increase of SO_3 content is indeed accompanied by an increase of combined water. In most soils, however, very little gypsum or other compound containing water of crystallisation is found.

The best thing to do, therefore, is to regard the difference between the amount of the loss on ignition and that of organic matter simply as "*combined water*."

Interpretation and Importance of Conversion into Milligramme-Equivalents.—Other suitable criteria for the chemical characterisation of soils—in addition to the percentage composition of the hydrochloric extract—are the absolute and relative (percentage) values of the milligramme-equivalents of the positive and negative constituents.

Some time ago I suggested* that it would be expedient and opportune in the case of soils to abandon the older dualistic composition and adopt a method more in keeping with the present advance of chemistry for expressing the chemical composition of the hydrochloric extract. Since in soils the positive and negative constituents usually occur in a solid phase and not in solution, I originally used the terms *positive* or *metal* and *negative* or *acid* radicals. When we consider, however, that the chemical character of soil constituents varies according to whether they react as "*cations*" or as "*anions*," we are justified nowadays in speaking of the positive constituents as "*cations*" and of the negative constituents as "*anions*." Even where the positive constituents occur partly, not in the form of well-defined mineralogical or chemical compounds, but in an absorbed state in the colloidal complex, it is more correct to speak of cations or positive elements, and anions or negative elements (or radicals) respectively than to speak of oxides or acid anhydrides that do not exist in soils at all. When GANSSEN† suggested the molecular reconstruction of the soil composition, he emphasised that the advantage of the molecular conversion was that this mode of expression suited both those who regarded the silicate complex dissolved in the hydrochloric extract as colloidal zeolites and real chemical compounds and those who—like STREMME—considered these colloidal complexes simply as irregular mixtures of SiO_2 and Al_2O_3. Today, however, according to WIEGNER, the latter supposition has been modified, it being held that the alumino-silicate acid gels figure as negatively charged nuclei surrounded by swarms of positively charged cations. Thus, in this case too, we use the cations—not the oxides of the bases—for the purpose of interpretation. The only moot point is whether the Al bound in the silicic acid nucleus has been precipitated as a positively charged Al_2O_3 gel by the negatively

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* See SIGMOND, ALEXIUS A. J. DE: "Introduction of a New Terminology in Indicating the Chemical Composition of Minerals and Soils" (Intern. Mitt. f. Bodenkunde, Vol. II., 1912, Nos. 2-3).

† See GANS (GANSSEN), R.: Int. Mitt. Bodenk., Vol. III. (1913), p. 529.

charged SiO_2 gel, or whether the Al—being partly an acidoid element (e.g., in aluminates)—entirely loses its positive character and in combination with the silicic acid forms a complex acid radical. We may expect the present rapid advance of colloid chemistry to clear up this question too, but until we have positive data we must presume the Al to be a positive constituent, particularly as the relevant experiments so far available prove that the Al_2O_3 and Fe_2O_3 gels themselves are slightly positively charged. Colloid chemists also explain the precipitation of the Fe_2O_3 gel by the SiO_2 gel as being the result of the coagulation of oppositely charged gels. The reason why I have felt impelled to deal with this question here is that GANNSEN emphatically stressed that the Al_2O_3 found in the hydrochloric extract was not a base, but was of acid character, and should therefore be placed not among the positive constituents (cations), but among the negative constituents (anions). We are, however, still faced with the question as to what silicic acid radical should be used to express the soluble SiO_2 included in the hydrochloric extract. My original supposition that the silicate complex decomposed by hydrochloric acid was derived largely from weathered silicates, the chief constituent of which might be presumed to be $Si(OH)_4$, has apparently been corroborated by my discovery that artificial zeolites—unexpectedly—also yielded an acid hydrate corresponding to $Si(OH)_4$.

Since, however, hot concentrated HCl partly decomposes even some unaltered silicate, there can be no doubt that the silicic acid of the hydrochloric extract does not entirely originate from ortho-silicic, but partly from meta- and poly-silicic acids, though the different components cannot at present be determined.

Another new value had to be introduced to meet cases in which the acid radicals found in soils were insufficient to counterbalance the equivalents of the cations. In such cases we obtain the so-called oxide residue by calculating the deficient equivalents as oxygen.

The equivalents may be expressed in grammes or milligrammes. The latter method is better because we thereby avoid the use of fractions. If we add up the milligramme equivalents of the cations, we get the *chemical equivalent of the A complex*. In humid soils, for instance, this figure averages about 356, and in arid soils about 715.

In carbonate soils this value may increase materially, even though they are not necessarily arid soils. In sandy soils, on the contrary, the A complex is small, consequently the sum of the milligramme equivalents is also very low. However, when we take into consideration all these circumstances, *the sum of the milligramme equivalents of the cations may serve to measure the relative amount of the A complex ; and it enables us to draw conclusions as to the degree of weathering and leaching.* For the latter purpose the percentage of the equivalents gives further evidence.

Table XX. illustrates the above principles by direct examples. When we examine the cation-equivalent percentage of the average

composition of the American humid and arid soils, we see first that, leaving out of account the relative amount of the manganese, the equivalent percentage of sodium is the lowest and that of aluminium is the highest. The equivalents of potassium ordinarily exceed those of sodium, though the opposite may happen also, depending partly on the leaching conditions and partly on the quality of the soil-forming silicates. Table XX. also shows that the sum of the monovalent is usually less than that of the bivalent equivalents. This is due to the fact that the leaching-out of the former is usually much easier than that of the latter. Moreover, in the arid soils the sum of the equivalent percentages of trivalent cations averages about 75, while in the humid soils this average value exceeds 90. If, however, the parent rock of the soil is rich in $CaCO_3$ a correction has to be made in estimating the leaching of the mono- and bi-valent cations.

2. The Chemical Characteristics of Soil Organic Matter.

The organic matter of the soil has its origin in the decay of the dead plant or animal substances incorporated in various ways in the soil. The decay of the soil organic matter is induced by soil microorganisms and is called humification, and the more or less dark-coloured product of these processes is called humus. Very often, however, the whole amount of organic matter of the soil is regarded as humus.

Theoretically, we may distinguish between the undecomposed original organic substances (such as carbohydrates, cellulose, hemicelluloses, lignin, pectins, fats and waxes, proteins, etc.), on the one hand, and the real product of humification, humus in the narrower sense of the term, the exact chemical composition of which is not yet known, though some of its properties can be defined and characterised chemically.

As the available methods do not enable us to determine exactly the total amount of organic matter in soils, we estimate it approximately by multiplying the total carbon content of the soil by the factor 1·724, corresponding to an average carbon content of 58 per cent. in soil organic matter.* The study of the humified part of the soil organic matter is very difficult because we have not yet been able to separate it in its original form from the non-humified fraction and from the inorganic part of the soil. The solvents (NH_4OH, $NaOH$, Na_2CO_3, pyridine) which are supposed to dissolve the humified organic matter, or acetylbromide, which dissolves natural plant material, but leaves the so-called " humus " complexes in the soil intact, have been used by various workers for estimating the humus content of the soil. WAKSMAN and his collaborators, however, rejected all these methods

* See WOLFF, E.: Ztschrft. anal. Chem., Vol. III. (1864), p. 85; Landw. Versuchsst. Vol. VI. (1865), p. 141; VAN BEMMELEN, J. M.: Landw. Versuchsst., Vol. XXXVII. (1890), p. 271.

as unsuitable and quite recently proposed a new one by which we may determine the approximate chemical composition of the bulk of the soil organic matter.* It may be noted also that GEDROIZ† and VERNANDER and SOKOLOWSKY‡ have suggested a method by which the soil is treated with neutral NaCl solution until the total humus is saturated with Na, the NaCl solution being then separated by dialysis from the dispersed humus. Though this method takes too long to make it convenient for analytical estimation, it separates the supposed "humus" in a neutral solution, avoiding all chemical interchange during the separation.

It is not easy today to decide which line of work is more rational. The study of the humus extracted by an alkaline solvent has a very rich literature and is very old.§ GRANDEAU proposed the term *matière noire*,|| as the name of the black substance extracted from the soil by an alkaline solution. According to SVEN ODÉN, accepting some of the amendments suggested by H. J. PAGE,¶ we may distinguish the following fractions:

Organic substances of the soil.

Non-humified matter (colourless).

Humified matter (coloured).

Soluble in cold, dilute alkali (Huminic acids).

Insoluble in cold dilute alkali (Humin, Ulmin subst., Humus carbon).

Soluble in water (Fulvic acids, Crenic acids).

Insoluble in water (Raw Humic acids).

Soluble in alcohol (Hymatomelanic acid).

Insoluble in alcohol (Humic acid).
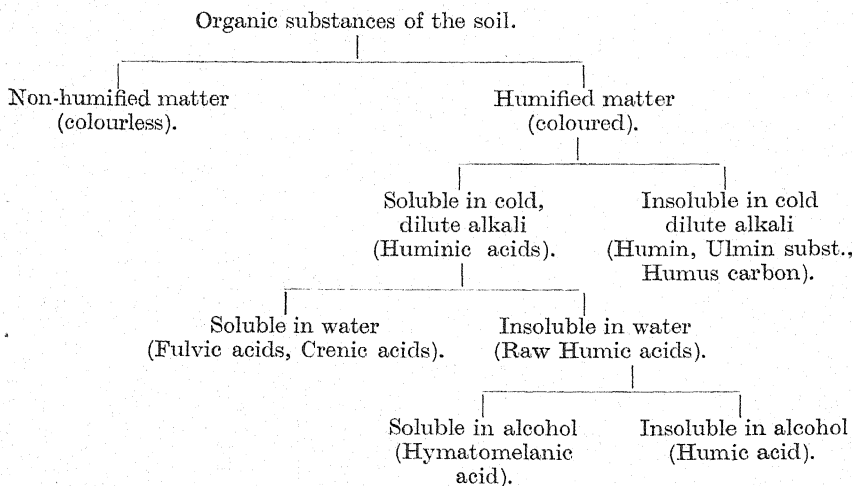
* See WAKSMAN, S. A., and STEVENS, K. R.: Soil Science, Vol. XXX., No. 2 (1930), p. 97.

† See GEDROIZ, K. K.: "Der absorbierende Bodenkomplex." Th. Steinkopff, Dresden-Leipzig, 1929, pp. ii, iii.

‡ VERNANDER, N. B., and SOKOLOWSKY, A. N.: Pap. Proc. I. Int. Congr. Soil Sci., Vol. III. (1928), p. 367.

§ ODÉN, S.: "Die Huminsäuren." Sonderausgabe aus Kolloidchem. Beihefte, Vol. XI., 2nd Edition, 1922. WAKSMAN, S. A.: Soil Sci., Vol. XXII. (1926), p. 123. FUCHS, W.: Kolloidztschr., Vol. LII. (1930), pp. 248 and 350; Vol. LIII. (1930), p. 124. MAYWALD, K.: "Organische Bestandteile d. Bodens." Blanck's Handbuch d. Bodenlehre, J. Springer, Berlin, Vol. VII. (1931), p. 113.

|| See GRANDEAU, L. "Recherches sur le rôle des matières organiques dans les phénomènes de la nutrition des plantes." Nancy, 1872; further on, Compt. Rend. d. l'Acad. d. Sciences, Paris, Vol. XX. (1872), p. 988.

¶ See PAGE, H. J.: Journ. Agric. Sci., Vol. XX. (1920), p. 455.

The " raw humic acids " correspond roughly to the *matière noire* of GRANDEAU. It should be noted, however, that the above-mentioned solvents hardly suffice to separate completely the given groups of organic matter. KEPPELER has shown* that alkali-soluble carbohydrates such as xylan, araban, and pectic acids are associated with the alkaline extract, and are not humified material. Fortunately, their amount in soils is ordinarily insignificant. On the other hand, a certain part of the humified organic matter, as we have seen, is not soluble in an alkaline solution. This part is thought to consist of modifications or anhydrides of the huminic acids and is called by various names in humus literature: humin, ulmin substance and humus carbon. If, however, we fuse this insoluble residue with alkali, we get the alkali salts of the so-called *huminic acids.* The carbon content of this humin material is roughly 65 per cent.

The alkaline extract of the soil contains the hypothetical huminic acids. By acidifying the alkaline extract we get a brown slimy precipitate comprising the so-called *raw humic acids,* the acid solution being found to contain the water-soluble *fulvic* or *crenic* acids. The carbon content of the latter is, as a rule, less than 55 per cent., and much lower than of the hymatomelanic and humic acids. The *fulvic* acids are regarded by SVEN ODÉN as a humified material of a lower grade than the hymatomelanic and humic acids, the humin or ulmin substances with their high carbon content being regarded as a further modification of the *raw humic* acids.

If we treat the acid precipitate of the alkaline solution with hot alcohol, we get in the solution the fraction called by ODÉN *hymatomelanic acid,* with an average carbon content of 62 per cent., and the insoluble, so-called *humic acid,* with a carbon content of about 58 per cent. ODÉN regarded both acids as real chemical compounds of constant composition, while, on the other hand, he supposed the fulvic acid fraction, as well as the humin fraction, to be mixtures of different organic compounds. Table XXV. includes some analytical data compiled from soil science literature by MAYWALD,† showing the chemical composition of various humus preparations.

The figures given do not show the proportion of oxygen, which can be estimated by difference as about 30-40 per cent. The variations are too large to justify us in suggesting any empirical formula for the chemical composition. The nitrogen content also varies very considerably. ODÉN‡ regards the nitrogen as an impurity and obtained pure fractions completely devoid of it. Other authors, however, assume that nitrogen is an integral component of the humic acids.

The solubility in alkali of the above acids may be regarded either as a true chemical salt-formation process producing water-soluble

* See KEPPELER, G.: Mitt. Ver. Fordg. Moorkult. in Dtsch. Reiche, Vol. XXXVIII. (1920), p. 3; see also Jhb. Landw., Vol. LXVIII. (1920), p. 53.
† See MAYWALD, K.: " Org. Bestandteile d. Bodens." Blanck's Handb. d. Bodenlehre, J. Springer, Berlin, Vol. VII. (1931), p. 163.
‡ See ODÉN, S.: *ibid.,* p. 101.

TABLE XXV

Authors.	Name of Substance.	Ultimate Composition.			References.
		C (Per Cent.).	N (Per Cent.).	H (Per Cent.).	
R. Hermann	Humic acid	57·5-58·3	6·5-7·0	4·8-5·2	J. prakt. Chem., 22, 68, 1841; 23, 379, 1841; 25, 193, 1842.
	Hymatomelanic acid	62·6-63·1	5·4-15·0	4·1-4·8	
	Pure humic acid	59·5-60·0	0·18	4·2-4·9	
W. Detmer	Peat humus at the surface	57·8	0·8	5·4	Landw. Versuchs St., 14, 248, 1871.
	7 feet deep	62·0	2·1	5·2	
	14 feet deep	64·1	4·1	5·0	
Malkomesius and Albert	Huminic acid of brown coal	60·0	1·1	4·4	J. prakt. Chem., 178, 509, 1904.
S. Odén	Humic acid	58·2	—	4·3	Die Huminsäuren. Koll. Beihefte, 1919.
	Hymatomelanic acid	62·2	—	5·3	
H. K. Ehlandt	Humic acid, I.	63·0	0·9	3·9	Die natürlichen Huminsäuren. Dissert. Breslau, 1924.
	Humic acid, II.	60·0	0·77	3·1	
	Humic acid, III.	62·9	0·7	4·7	
Stadnikow and Korschew	Humic acid (Merck)	58·6	3·6	4·9	Koll. Zschft., 47.
A. Schmuck	Soluble huminic acid	62·2	3·4	4·2	Pedology (Moskva), 25, 36, 1930.
	Insoluble huminic acid	61·8	3·3	4·2	

alkali humates, or as a colloidal dispersion in an alkali solution. ODÉN's arguments in favour of it being a true salt formation are as follows:*

The degree of dissociation of a $N/10$ ammonia solution is very low (about 5 per cent.), and its electrolytic conductivity is consequently much less than that of a fully dissociated ammonium salt solution of the same normality. If we add increasing quantities of $N/10$ ammonia solution to equivalent quantities of humic acid suspension on the one hand, and on the other mix the same quantities of ammonia solution with corresponding quantities of distilled water, theoretically three kinds of reaction are possible:

1. If there is no reaction between ammonia and humic acid, the conductivity of both solutions at equal ammonia concentrations should be the same, or nearly so.

2. If the ammonia is absorbed by the humic acid, the conductivity of the humic acid suspension should be less than that of the aqueous solution.

3. If, on the other hand, humic acid in suspension is a true acid, an ammonium salt solution will be formed, whose conductivity will be much greater than that of the aqueous ammonia solution.

ODÉN found that the third reaction took place, proving that his humic acid preparation *was apparently a true acid*. Furthermore, he determined also the equivalent weight of his " pure " substances partly by conductometric, partly by potentiometric titration,† and obtained for his humic acid values of about 339 by conductometric and about 345-350 by potentiometric determination. Both values correspond fairly well to the equivalent weights 320-332, which he calculated from the chemical analysis of Ca and Ba humates. The corresponding value for hymatomelanic acid was found to be lower, about 250.

On the basis of viscosimetric determinations ASSARSSON‡ concluded that humic acid must be tetravalent, and would therefore have a molecular weight of about 1,350. It may be noted that similar values have been found by SAMEC.§

WAKSMAN and his co-workers treat the humus question from an entirely different point of view. The fundamental idea of WAKSMAN's theory is the hypothesis that the bulk of humus-forming materials‖ originates not from the whole organic matter of the soil, but from the lignin and protein. " The average chemical composition of the organic matter of six soils according to WAKSMAN's analyses¶ gave 43·27 per

* See ODÉN, S.: *ibid.*, p. 73.

† See ODÉN, S.: *ibid.*, pp. 85, 87, 89.

‡ See ODÉN, S.: *ibid.*, p. 92.

§ See SAMEC, M.: Koll. Ztschrft., Vol. LI. (1930), p. 96.

‖ See WAKSMAN, S. A.: Transactions of the II. Comm. of the Inter. Soc. Soil Sci., Budapest, 1929, Vol. A, p. 179.

¶ See WAKSMAN, S. A., and IYER, K. R. N.: Soil Sci., Vol. XXXIV. (1932), p. 47.

cent. lignin ('lignin-humus-complex' or 'soil lignin'), 33·81 per cent. protein or organic nitrogenous complexes, 11·02 per cent. water-insoluble carbohydrates (cellulose, hemicelluloses, etc.), and 2·77 per cent. ether and alcohol-soluble substances, thus accounting for 90·87 per cent. of the total organic matter of the soil. Of the organic matter accounted for 78·08 per cent. was made up of two complexes, namely the protein and the lignin. The same is true of low moor and sedimentary peats* and of well decomposed manure.† We are justified in concluding that the humus of mineral soils, of well-decomposed peats, and of composts, consists predominantly of two chemical complexes, namely lignins and proteins, with an admixture of other substances such as fats and waxes, cellulose and hemicelluloses, organic acids and alcohols; the nature and abundance of these accompanying substances depend upon the nature of the plant and animal residues added to the soil or used in making the compost, upon the extent of their decomposition, and upon the conditions under which this decomposition takes place, such as reaction, moisture content, aeration, and temperature. Whether the two major complexes, namely the lignins and proteins, form one chemical complex in humus, or whether they exist independently, still remains to be determined." I have quoted this part of the original publication to reproduce exactly the fundamental idea of WAKSMAN's humus theory. In the same publication he reports experiments which tend to show that the lignin and protein fractions form the so-called "humus nucleus" of the author in which apparently the two initial substances have certain chemical affinities. "This may be looked upon," we are told,‡ "as a more modern paraphrase of the earlier conception of 'humus acids' on the one hand, and of 'humus' and 'crenic' or 'fulvic acids' on the other; or the more recent conception of 'humic substances' on the one hand, and of 'non-humic compounds' on the other."

The experiments made by WAKSMAN and IYER show that the lignin exercises a depressive effect upon the decomposition of proteins in pure and mixed cultures of micro-organisms, not owing to any toxic action of the lignin, but on account of a chemical interaction between the lignin and protein molecules. The same results have been obtained in our laboratory.§ We found that the best results were secured by adding 40 per cent. casein to 60 per cent. alkali lignin in alkaline solution, and even then we could not recover more than 33-25 per cent. of the nitrogen of the original casein. The rest was bound by the lignin complex.

* See WAKSMAN, S. A.: Amer. Jour. Sci., Vol. XIX. (1930), pp. 32-54.
† See WAKSMAN, S. A. and McGRATH, J. M.: Amer. Jour. Bot., Vol. XVIII. (1931), pp. 577-581.
‡ See WAKSMAN, S. A., and IYER, K. R. N.: Soil Sci., Vol. XXXIV. (1932), p. 48.
§ See KOVÁSZNAY, R.: "Lignin befolyása fehérjék bontására." Budapest, 1934. Inaugural dissertation for the doctor degree worked out in the soil laboratory of the University of Technical Sciences at Budapest.
‖ See loc. cit. above.

WAKSMAN and IYER have compared‖ some characteristics of the lignin-protein complex with those of the α-humus prepared from soil by extraction with alkali and by precipitation with acid, and obtained the following results:

	α-Humus.	Humus Nucleus or Ligno-proteinate.
Nitrogen content	2-3 per cent.	2-3 per cent.
Combination with bases ..	Combines readily	Combines readily.
Solubility in dilute alkali solution	Soluble	Soluble.
Solubility in dilute mineral acids	Insoluble	Insoluble.
Oxidation by H_2O_2 ..	Readily oxidised	Readily oxidised.
Oxidation by acetyl bromide	Only slightly oxidised	Not fully oxidised.
Decomposition by micro-organisms	Attacked with difficulty	Attacked with difficulty.
Influence on microbial processes	Favourable	Favourable.

From these we see that the α-humus, which corresponds almost exactly to GRANDEAU's *maitère noire* differs only in possessing more resistance to the oxidising action of acetyl bromide, the other characteristics of the ligno-proteinate being practically the same as those of the α-humus.

The authors also give a schematic representation of the mechanism of humus formation during the decomposition of plant residues in the soil; as well as an approximate formula for the chemical condensation of the lignin and protein molecules. They note, however, that the exact chemical nature of the *ligno-proteinate complex* or *humus nucleus* remains to be studied; " its nature varies with the nature of the lignin and proteins used, relative concentrations of these two substances, reaction at which precipitation takes place, relative concentration and nature of bases, degree of drying, and a number of other factors."[*]

Recently ANDRÉ SCHMUZIGER,[†] and I. I. THERON and P. LE R. VAN NIEKERCK[‡] have applied WAKSMAN's method for testing various soil profiles. Both papers contain some interesting results, but it is not the aim of this book to discuss these questions in detail.

It will be seen that the humus question is still an open one. There are still many contradictions which have to be reconciled in this field of work; nevertheless, certain deductions can be drawn from it which are useful for the chemical characterisation of soils.

The acid character of the product of humification is no longer doubtful, and the pedological rôle of soil humus is closely connected with this acid character. Its importance is much enhanced by the

[*] See WAKSMAN, S. A., and IYER, K. R. N.: *loc. cit.*, p. 67.

[†] See SCHMUZIGER, ANDRÉ: "Über die Verteilung und den Chemismus der Humusstoffe in den Profilen einiger schweizerischer Bodentypen." Promotions-arbeit, an d. Eidgenössischen Techn. Hochschule Zürich. Turbenthal, 1935.

[‡] See THERON, I. I., and P. LE R. VAN NIEKERK, South African Journ. of Sci., Vol. XXXI. (1934), pp. 320-346.

mobility of humus substances in soils. This enables these so-called "humic acids," "humus-nucleus," etc., to take a *very active part* in soil leaching and accumulation processes, partly as chemical agents, partly as protective colloid material. The *absorption phenomena of soils* are also—as we shall see later on—quite *closely connected with the acidoid character of these humic acids*, and in this respect it is indifferent which of the above-mentioned theories proves to be correct.

Besides, the total quantity of organic matter, its distribution in the soil, and the rate of humification have important effects on soil texture, and it is therefore necessary to know the proportions of these organic substances.

The total amount of organic matter can be roughly estimated by multiplying the total C content of the soil by the factor 1·72. It is, however, not so easy to select reliable methods of determining the rate of humification and decomposition of the total organic matter, or the quality of the products of humification. The determination of GRANDEAU'S *matière noire* has recently been supplemented by SPRINGER, who proposes some new terms and methods* which may compete with those of WAKSMAN and his co-workers. In both cases there are many details open to criticism. If, however, we determine the C content and N content of the alkaline humus extract of the soil by HILGARD's method as modified and applied by L. KOTZMANN,† we may get an approximate estimation of the humified part of the soil organic matter resistant to microbial agents, yet representing chemically and physico-chemically the active part of the organic matter; for it is highly probable that in the absorbing complex of the soil the organic part is formed from this fraction.

NOTE.—This section was contributed to the original Hungarian edition by L. KOTZMANN, who was my assistant at that time, but since he left this position, the literature on soil organic matter has increased materially and I have been obliged to rewrite the whole section.

3. Characteristics of the Absorbing Complex (Humus-Zeolite Complex).

The absorption phenomena of the soil have long been familiar to us.‡ In previous chapters we have seen that during soil formation—as a result partly of the humification of decayed organic substances and partly of the weathering of silicates—there comes into being that soil complex which is the site of the most important absorption phenomenon —viz., *base-exchange* or *cation-exchange*—and for that reason might be termed *absorbing complex* or, in view of its origin and composition, *humus-zeolite complex*.§ VAN BEMMELEN distinguished three kinds

* See SPRINGER, U.: Ztschrft. Pflanzenernährung Düngung u. Bodenkunde, Part A, Vol. XXII. (1931), p. 135; and in Soil Research, Vol. III. (1932), p. 39.
† See KOTZMANN, L.: Mezög. Kutatások, Vol. I. (1928), p. 21.
‡ For a brief historical description, see SIGMOND: Mathem. és. Term. Tud. Ert., Vol. XLIII. (1926), p. 51.
§ See SIGMOND: *loc. cit.*

of adsorption—purely physical binding (*adsorption*), purely chemical binding, and physico-chemical binding (*absorption*). Recent physico-chemical and more particularly colloid-chemical researches have shown that there is a similarity between purely physical and purely chemical adsorption. As a consequence, most scientists call all adsorption phenomena adsorption, while the idea of absorption recommended by VAN BEMMELEN to express physico-chemical adsorption is going out of use, though there can be no doubt that it is far simpler to speak of absorption than of physico-chemical adsorption. So, where later on we speak of absorption or absorbing complex, the term will apply everywhere only to that group of adsorption phenomena the principal feature of which is base exchange. As we have seen, these exchange phenomena play a significant rôle in the processes of soil formation, though they have an equally characteristic effect upon the present dynamics and the probable future behaviour of the soil.

The fact that the characteristics of the absorbing complex—which are easily definable chemically—reproduce what are practically the past and the present dynamic conditions of the soil and allow us to foresee phenomena to be expected in the near future has made the absorbing complex a very important medium in soil dynamic researches—so important as to have led certain soil students to base their whole soil system on it.* However, before dealing in detail with the "*humus-zeolite complex*," I must give a short description of the whole field which comprises it—*i.e.*, of the general adsorption phenomena of the soil. GEDROIZ, one of the scholars of recent years who have exhaustively studied these phenomena in soils, divided them into five groups— viz., (1) mechanical, (2) physical, (3) physico-chemical, (4) chemical, and (5) biological adsorption.

Between the purely physical and the purely chemical adsorption we have the so-called *physico-chemical adsorption*, which VAN BEMMELEN termed absorption.

A common feature of all absorption phenomena is that their existence depends upon the presence in the soil of certain special materials. Thus, for example, quartz, apatite, calcium carbonate, gypsum and other well-defined mineral or chemical materials do not show absorption phenomena—or at most only mechanical, physical or chemical adsorption. In the same way pure $Al_2(OH)_6$, $Fe_2(OH)_6$ and silicic acid gels do not show any reactions corresponding to absorption phenomena— *i.e.*, to *base* or *cation exchange*. These phenomena are not in evidence except in the presence of the so-called *absorption complex*.

It is true, of course, that according to certain data found in soil science literature there are original minerals—silicates—that also show slight base-exchange properties; this being in every single case attributable to the presence of an absorption complex formed on the surface. It is very probable, however, that this does not apply to

* See GEDROIZ, K. K.: "Die Lehre vom Adsorptionsvermögen der Boden" (Th. Steinkopff, Dresden and Leipzig, 1931).

natural zeolites or—possibly—even to the mineral compounds with crystalline structure recently discovered in the colloidal fractions. The absorbing complex may be regarded either as a chemical compound of a complex anion formed with various cations or—as we shall see later on—as the solid phase of a colloidal dispersion charged electronegatively at the surface, though surrounded by an electropositive ring of ions.   The positively charged part may be exactly determined and is well known; it consists of the absorbed cations.   Our knowledge of the negatively charged complex is, however, rather deficient.

The absorbing complex is formed partly from the humus substances produced during the decomposition of dead organic matter, partly from new substances produced by interaction of the constituents SiO_2, Al_2O_3 and Fe_2O_3 formed during the weathering of silicates in the presence of various bases (CaO, MgO, K_2O and Na_2O) or from the products left behind by the partial decomposition of the original silicates.*

The former hypothesis that the inorganic part of the absorbing complex is nothing more than a simple mixture of SiO_2, Al_2O_3 and possibly Fe_2O_3 gels is not valid, if only because the solubility of such mixtures in weak alkalies or acids is quite different from that of the soil absorbing complex.   The formation of artificial zeolites shows that the SiO_2 and Al_2O_3 precipitated as artificial zeolite from alkaline solution have to some extent lost their solubility.   Soils usually contain only very minute quantities of SiO_2 and Al_2O_3 directly soluble in alkaline solutions, even where the absorbing complex is considerable.   According to GEDROIZ only the so-called soloti soils contain any considerable quantity of alkali-soluble SiO_2.   The so-called " soluble " SiO_2 is only the result of a previous decomposition by HCl.   Of interest in this respect are the experiments made by BRADFIELD,† who separated from a subsoil the so-called colloidal clay, which is the nearest approach in composition to the absorbing complex, and determined the total amount of SiO_2, Al_2O_3 and Fe_2O_3 present.   He also prepared an artificial mixture of Al_2O_3, Fe_2O_3 and SiO_2, which had been carefully purified and mixed in the same proportions as in the clay; he then treated both separately with HCl and NaOH of the same concentration and determined the dissolved substances.   The results are shown in Table XXVI., in which I. denotes the natural clay and II. the artificial mixture.

The data given prove beyond a doubt that there is no similarity between the natural colloidal clay complex and a similar artificial mixture of the three components.   Consequently, though this does not prove that the so-called colloidal clay examined by BRADFIELD consists of a single aluminium silicate, it is nevertheless clearly shown that it cannot be regarded either as a simple physical mixture of SiO_2, Al_2O_3

* See GEDROIZ, K. K.: " Der adsorbierende Bodenkomplex " (Th. Steinkopff, Dresden and Leipzig, 1929), p. 6.

† See BRADFIELD, R.: Journ. Amer. Soc. Agronomy, Vol. XVII. (1925), p. 256.

TABLE XXVI

		SiO$_2$.	Al$_2$O$_3$.	Fe$_2$O$_3$.
Composition of the original materials	I.	59·1	31·9	9·1
	II.	59·1	31·9	9·1
Composition of the materials after treatment with:				
Concentrated HCl	I.	0·2	31·6	9·1
	II.	Completely dissolved, or in colloidal solution.		
5 per cent. HCl	I.	7·3	15·7	3·8
	II.	Completely dissolved.		
0·13 normal HCl	I.	7·7	5·8	1·6
	II.	Al$_2$O$_3$ and Fe$_2$O$_3$ apparently dissolved, SiO$_2$ in colloidal solution.		
0·13 normal NaOH	I.	9·0	5·7	—
	II.	A stable " sol "-solution.		
1 per cent. NaOH	I.	13·3	7·6	—
	II.	33·6	21·6	—

and Fe$_2$O$_3$ gels. There must be some more deeply rooted combination which may indeed be partly physical in character and connected with the high dispersion of the colloidal fraction, but is undoubtedly due also to chemical interactions which differentiate this complex from the mixture of similar proportions of the pure colloidal gels.

The electropositively charged part of the absorbing complex can, on the other hand, be much more precisely determined; for the mutual and equivalent exchange of cations enables us to exchange the whole quantity of absorbed cations and to determine the same both quantitatively and qualitatively. Of late soil science literature has been enriched with numerous valuable data on this point. The relevant fundamental principles were first definitely formulated in international soil science literature by HISSINK.* HISSINK's S-value, which represents the total of the equivalents of the absorbed metal cations; his T-S-value, which gives the measure of the so-called *unsaturation* of the absorbing complex in H equivalents; and the V-value, which is the measure of the degree of soil saturation, are all fundamental values which, though known to earlier writers, were first exactly defined by HISSINK.

HISSINK starts by assuming that the exchangeability of the bases enables us to determine with more or less certainty their amount, and that, since the bases are exchanged in chemically equivalent quantities, a calculation of the total equivalents of exchanged bases enables us to determine the quantity of equivalent metal cations absorbed in the

* See HISSINK, D. J.: Int. Mitt. Bodenk., Vol. XII. (1922), p. 81.

absorbing complex. This HISSINK calls the S-value, a term which has already become an almost universally accepted term in international soil science literature, a fact which is eloquent proof of the correctness of the definition. But previously there had developed an opinion—particularly in connection with highly acid fen soils—that acid soils do not contain as many absorbed bases as their absorption capacity would enable them to absorb; meaning that chemically they may be regarded as similar to unsaturated compounds such as acid salts, which may be saturated by neutralisation with alkalies, forming neutral salts. The amount of bases corresponding to the maximum degree of saturation (expressed in chemical equivalents) HISSINK calls the T-value, employing the formula T-S to denote the equivalents needed to saturate the soil completely. The fact that in HISSINK's studies the value T figures only indirectly is due to his not having originally had at his disposal any acceptable method for its direct determination. So HISSINK first determined the S-value in soils and then by separate neutralisation the T-S-value, the sum of these being T, a value which GEDROIZ called *absorption capacity*, and regarded, from the results of numerous experiments, as one of the most characteristic values of the absorbing complex, and a value which under normal conditions is permanent.*

It is true, indeed, that we cannot determine this value with the same certainty as the S-value, though the determination of the latter is also not always exact, there being a variety of opinions as to which of the known methods gives the most reliable results.

However, these principles may be defined as follows: the T-value (the *absorbing capacity* of the soil) expresses the maximum number of base and hydrogen equivalents—or of all cations—which the absorbing complex is able to take up, or chemically speaking *the valency of the complex*.

Finally, HISSINK expressed the degree of saturation (V) in percentages by the following formula:

$$V = \frac{S}{S+(T-S)} \cdot 100 = \frac{S}{T} \cdot 100.$$

This shows the percentage of the equivalents of the absorbing complex saturated with metal cations. The V-value is therefore the measure of the saturation of the soil, or the complementary value of the unsaturation. For knowing the value of V, the degree of unsaturation is given by 100-V. For instance, if the coefficient of saturation V=70, then the coefficient of unsaturation will be $100-70=30$. This means that 30 per cent. of the total capacity of the absorbing complex is occupied by hydrogen ions.

Now let us examine the real importance in soil science of each of these values.

A thorough study of the earlier literature dealing with base exchange

* See GEDROIZ, K. K.: *op. cit.*

shows that, while some investigators were of opinion that the base exchange conforms to the law of equivalents, others apparently found just the opposite. Assuming that the experiments were correct, the contradiction is only apparent and may be explained by the fact that there are soils not completely saturated with bases which, when treated with certain neutral salts, seemingly absorb a larger number of bases than corresponds to the total equivalents of the exchanged bases. If we treat an unsaturated soil (e.g., an acid forest soil) with a known quantity of NH_4Cl, and after determining the quantity of dissolved bases add up their equivalents and compare them with the equivalents of ammonia absorbed, we shall find that the equivalents of the absorbed ammonia exceed those of the exchanged bases. This was formerly taken to prove that this kind of soil absorption does not always follow the rules of chemical equivalence. Now we know that the excess absorbed ammonia originates owing to the ammonia dissociating hydrogen from the absorbing complex, the originally neutral salt solution becoming slightly acid owing to the presence of hydrogen ions equivalent to the excess absorbed ammonia. Practically the only part of the NH_4Cl absorbed by unsaturated soils is the ammonia, hydrogen equivalent to the ammonia absorbed being set free in addition to the exchanged bases. The original Cl content of the ammonium-chloride solution does not change; but the hydrogen unites with the Cl to form hydrochloric acid which, being a strong electrolyte, is completely dissociated, the result being that the solution shows an acid reaction. However, if the soil was originally saturated, the amount of absorbed ammonia does actually correspond to the sum of the equivalents of the dissolved metal cations, as has recently been proved by the experiments of GEDROIZ. Thus the exchange is in full conformity with chemical laws and may be expressed by the following equation:

$$\text{T. CaMg} + 4NH_4Cl \rightleftharpoons CaCl_2 + MgCl_2 + \text{T. } 4NH_4.$$
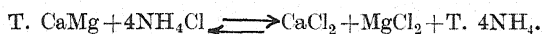
The arrows pointing in different directions denote that the reaction is reversible and consequently incomplete, i.e. we have here a mobile equilibrium varying according to the conditions—namely, (1) the concentration of the ammonium chloride, and (2) the ratio between the soil and the ammonium chloride.

There is another striking feature of the exchange reaction which must be emphasised—viz., that it is almost instantaneous. This phenomenon is attributable to the fact that the reaction takes place on, and is confined exclusively to, a relatively large surface. GEDROIZ, for instance, states that the amount of CaO dissolved from a soil in a minute is the same as that dissolved in 30 days.* In practice this means that the exchange equilibrium may also be attained during the time required for a salt solution to percolate through the soil, and that repeated

* See GEDROIZ, K. K.: op. cit., p. 360.

percolations will in certain cases cause complete base exchange. If a salt solution is continually percolated through a soil, all the bases are exchanged in a comparatively short time.

GEDROIZ experimented with many different salt solutions, and showed that the soil may by exchange take up any metal cation and ultimately absorbs the same number of equivalents of each. This proves that *the capacity of the absorbing complex of the soil is a constant.* Such one-sidedly saturated soils have been prepared by KOTZMANN, who has found that calcium soils, for instance, behave physically quite differently from sodium soils.* *The exchange energy of the various cations also shows considerable divergence.* This energy GEDROIZ calls *adsorption energy.*

Here again I must refer to GEDROIZ's data, which illustrate this matter from all points of view. GEDROIZ prepared with $BaCl_2$ an artificial barium soil with which experiments were carried out under absolutely similar conditions; in each case 10 grammes of barium soil were subjected for two days to the action of 100 grammes of 0·1 normal salt solution, the quantity of Ba in the solution being then determined. By simple multiplication the equivalents absorbed or exchanged could then be calculated (see Table XXVII.).

TABLE XXVII

Salt Solution.			Exchanged Ba in Percentage of the Soil.	Corresponding mg. Equivalents.
LiCl	..	..	0·522	3·8
$(NH_4)Cl$	..	..	0·886	6·5
NaCl	..	..	0·625	4·5
KCl ..	..	..	0·932	6·8
RbCl	..	..	1·062	7·8
$MgCl_2$	..	..	1·058	7·7
$CaCl_2$	..	..	1·400	10·2
$CdCl_2$	..	..	1·505	11·0
$CoCl_2$	..	..	1·545	11·3
$AlCl_3$	..	..	2·291	16·7
$FeCl_3$	..	..	2·492	18·7

The above data show that the cations differ greatly in respect of their *exchange or adsorbing energy*, which increases on the one hand with the valency and on the other with the atomic weight of the cations. For instance, if we compare the increase in the atomic weight of the monovalent cations with their absorbing energy, we see that, except in the case of NH_4, increase of atomic weight is accompanied by an increase of the absorbing energy. Ammonium is to a certain extent an exception, as it stands second only in respect of molecular weight, but its energy exceeds that of sodium and stands quite close

* See KOTZMANN, L.: Mezőgazd. Kut. (Agricultural Researches), Vol. V. (1932), p. 427.

to that of potassium. In the case of bivalent cations the absorbing energy of Mg is slightly less even than of Rb but is decidedly greater than of K, though its atomic weight is far less than that of K and approximates that of Na. But the absorbing energy of Ca is far greater than of any monovalent metal cation. Cd and Co are of no particular importance in soil science. But the great absorbing energy of Al and Fe—a circumstance primarily due to their trivalence—is noteworthy. These phenomena originate from the differences in intensity with which water molecules are attracted by the cations. According to RAMANN and WIEGNER the absorbing energy increases in proportion to the decrease of hydration of the ions. Thus the absorbing energy increases as shown in the lyophile series of cations. The only exception is hydrogen, the absorbing energy of which is higher than of all other cations. GEDROIZ, for instance, determined the amount of barium exchanged from tschernosem saturated with barium after treatment with 0·01 normal NaCl, CaCl₂ and HCl.

NaCl	0·041 per cent.	BaO calculated to the soil.					
CaCl₂	0·165 ,,	,,	,,	,,	,,	,,	,,
HCl	0·706 ,,	,,	,,	,,	,,	,,	,,

These data show that under the given circumstances the adsorbing energy of the H ions is 17 times as great as that of the Na ions and 4 times as great as that of the Ca ions. RAMANN studied the effect and equilibrium of mixed salt solutions, but his investigations were never finished.*

On the basis of the absorbing complex we may distinguish between *saturated* and *unsaturated* soils. Saturated soils are those in the absorbing complex of which all valencies are occupied by metal cations, or, in other words, those in which the absorbing capacity is completely occupied by metal cations. Unsaturated soils, on the other hand, are those in the absorbing complex of which the metal cations are partly replaced by hydrogen. In nature, however, we do not find the working of such strict rules.

This is particularly true when different methods are employed to determine unsaturation. Some years ago DI GLERIA and the present writer showed† that different degrees of unsaturation are obtained according to the method employed. At that time we found conducto-metric titration to be the best method; but even this procedure made the Hungarian tschernosems appear to be unsaturated. This anomaly is to be attributed to the fact that in the case of saturated soils conducto-metric titration is not very reliable, giving too high values of un-saturation. Recent investigations carried out by DI GLERIA and

* See RAMANN, E.: Zeitschrift anorg. allg. Chem., Vol. XCV. (1916), p. 115; Vol. CV. (1918), p. 81; Vol. CXIV. (1920), p. 90; Act. IV. Confer. Intern. Pédologie, Rome, Vol. II. (1924), p. 383.

† See SIGMOND, E., and DI GLERIA, J.: Math. és Term. Tud. Ert. (Mathematics and Natural Science Transactions), Vol. XLIV. (1927), p. 535.

KOTZMANN have shown that it is better to employ the ammonia absorption method to determine the unsaturation—*i.e.*, the U-value. This procedure has, indeed, shown that there is not more than 1-2 per cent. of H equivalents in the complex of saturated steppe soils, the slight deviations being due to defects of the experimental method.* This may be seen from the data in Table XXVIII., which contains the relevant values of two typical profiles of Hungarian tshernosems. For the sake of comparison the Table shows also the values obtained by conductometric titration.

TABLE XXVIII

Soil.		S (Hissink).	Degree of Unsaturation titrated conductometrically.			Degree of Unsaturation determined by Ammonia Absorption.		
Name.	Depth (cm.).		T-S.	T.	Hydrogen Equivalent (Per Cent.).	U.	T.	Hydrogen Equivalent (Per Cent.).
Mezőhegyes	0–30	21·55	6·12	27·67	22·12	0·4	21·95	1·82
	30–60	15·90	4·36	20·26	21·52	0·3	16·20	1·85
	60–90	15·58	3·22	18·80	17·13	0·1	15·68	0·63
	90–120	16·67	2·42	19·09	12·68	0	16·67	0
	120–150	9·01	1·92	10·92	17·49	0	9·01	0
Gyula	0–30	17·80	2·89	20·69	13·97	0·2	18·00	1·11
	30–60	16·56	2·60	19·16	13·57	0·2	16·76	1·19
	60–90	14·24	2·33	16·57	14·06	0·2	14·44	1·38
	90–120	13·46	1·98	15·44	12·82	0	13·46	0
	120–150	9·50	1·06	10·56	10·04	0	9·50	0

In the absorbing complex of unsaturated soils, on the other hand, the H plays a leading part, and its relative quantity—expressed in equivalent percentage of the T complex—is usually far in excess of 1-2 per cent. A few examples of this in some Hungarian soils are shown in Table XXIX.

In both saturated and unsaturated soils the Ca cation usually predominates over the other metal cations. This may be seen best when we express the exchangeable metal cations in equivalent percentages (S) of the total number of metal cations, as in Table XXX.

The data given show that in the upper horizons the Ca cations are far in excess of the other metal cations. Next in order is Mg, while in the upper horizons the alkalies (K and Na) usually play a very subordinate part. GEDROIZ is of opinion that owing to the trifling quantity in which they are present the latter may be entirely ignored. However,

* See DI GLERIA, J., and KOTZMANN, L.: Mezőgaz. Kut. (Agricultural Researches), Vol. V. (1932), p. 270.

TABLE XXIX

Soil.		S. (Hissink).	Degree of Unsaturation titrated conductometrically.			Degree of Unsaturation determined by Ammonia Absorption.		
Name.	Depth (cm.).		T.-S.	T.	Hydrogen Equivalent (Per Cent.).	U.	T.	Hydrogen Equivalent (Per Cent.).
Hüvösvölgy Jánoshegy	0–30	6·3	9·6	15·9	60·38	4·8	11·1	43·24
	30–60	14·8	14·9	29·7	50·17	5·9	20·7	28·50
	150–180	13·4	3·4	16·8	20·24	0·5	13·9	3·59
Kotus soil	0–30	58·70	38·70	97·40	39·73	47·9	106·60	44·93
	30–60	35·60	13·75	49·35	27·86	7·4	43·00	17·21
	60–90	29·99	10·61	40·60	26·13	3·9	33·89	11·51
	90–120	29·53	10·21	39·74	25·69	3·5	33·03	10·59
	120–150	29·21	9·40	38·61	24·54	3·2	32·41	9·87

TABLE XXX

Soil.		S. (Hissink).	mg. Equivalent in Per Cent. of S.			
Name.	Depth (cm.).		Ca.	Mg.	K.	Na.
Mezöhegyes ..	0–30	21·55	86·64	11·19	0·79	1·48
	30–60	15·90	76·10	19·18	1·64	3·08
	60–90	15·58	49·55	44·99	2·05	3·41
	90–120	16·67	23·51	66·05	2·46	7·98
	120–150	9·01	21·65	59·60	4·77	13·98
Gyula	0–30	17·80	81·69	10·17	7·47	0·67
	30–60	16·56	80·62	11·35	4·77	3·26
	60–90	14·24	59·76	23·18	10·04	7·02
	90–120	13·46	8·55	55·65	26·67	9·13
	120–150	9·50	—	59·79	27·16	13·05
Kotus soil ..	0–30	58·70	83·03	12·77	2·16	2·04
	30–60	35·60	84·77	12·42	1·40	1·41
	60–90	29·99	78·53	17·53	1·47	2·47
	90–120	29·53	75·76	20·79	1·25	2·20
	120–150	29·21	75·80	21·88	0·72	1·60

investigations made in Hungary and elsewhere prove that we cannot ignore the *exchangeable potassium*, which indeed plays a very important rôle as a plant nutrient. In acid unsaturated soils exchangeable Al

and Fe are also quite frequent, but their rôle and importance have not yet been clearly defined, nor do we yet know exactly to what their presence is ultimately due.

Before proceeding, it will be well to discuss shortly why in the above cases calcium came to play a leading rôle among the cations in the absorbing complex, as also why the unsaturated soils contain so much hydrogen.

From GEDROIZ's experiment we have learned that the absorbing energy of H is four times as great as of Ca. Consequently, were the ion concentration of the H and Ca in the soil solution the same, the H would undoubtedly prevent the Ca from entering the complex. But the H-ion concentration of the soil solution is very low so long as the soil reaction is neutral or slightly alkaline. This is true of steppe soils which are normally calcareous in origin and contain sufficient Ca to maintain the neutrality of the medium; hence the concentration of the Ca ions is far greater than of the H ions, and only a very small amount of H is able to enter the absorbing complex. However, as soon as the bases of the soil have been leached to an extent enabling the energy of the H ions to assert itself, the soil solution becomes acid and more H ions penetrate into the absorbing complex. The concentration of the H ions may be considerably increased by the CO_2 and the so-called humic acids produced during the decomposition of organic matter. It is true, indeed, that even in strongly leached soils the concentration of H ions never exceeds that of the metal cations, but the superior absorbing energy exerted by the H ions enables them notwithstanding to assert themselves. If this were not so, there could never be any metal cations at all in the absorbing complex of acid soils. Nor must we forget that while on the one hand the decomposition of organic matter increases the concentration of H ions, on the other hand chemical weathering of mineral materials produces many metal and OH ions, thus lowering the concentration of the H ions.

Probably the Al and Fe ions enter among the exchangeable cations as the result of the zeolitic part of the absorbing complex becoming slightly decomposed in presence of a high concentration of H ions; in this way Al and Fe ions may enter the soil solution and as a consequence of their high absorbing energy may be taken up by the absorbing complex in the form of positively charged metal cations.* In a slightly alkaline medium, however, the Al and Fe ions are precipitated as hydroxides, for which reason Al and Fe are never found among the exchangeable bases of steppe soils.

In the upper horizons the Na cation usually plays only a subordinate rôle, possessing as it does a smaller absorbing energy than any other of the absorbed cations present in the soil. However, where there are obstacles impeding the process of leaching, sodium may accumulate in the lower horizons even of steppe soils, while in alkali soils it actually plays a decisive rôle in the upper horizons also.

* Cf. KAPPEN, H.: " Die Bodenazidität " (J. Springer, Berlin, 1929).

Table XXXI. shows the proportions of the exchangeable cations found in various Hungarian and other soils (the data are partly the hitherto unpublished results of researches made by ARANY).

In certain cases we find Mg cations accumulating in addition to Na. We do not yet know the exact circumstances governing the accumulation of Mg, and it would be premature to discuss the separate pedological properties of Mg soils. On the other hand, we are perfectly familiar with the special properties of Na soils, which constitute a group of their own.

TABLE XXXI

Origin of the Soil.	Depth (cm.)	S.	Exchangeable Cations in Percentage of the S-value.			
			Ca.	Mg.	K.	Na.
Fresno, Cal. 19 ..	0–30	5·75	36·2		6·2	57·6
	30–60	5·87	49·9		1·5	48·6
	60–90	6·19	54·8		1·3	43·9
	90–120	6·70	56·4		1·5	42·1
Fresno, Cal. 17 ..	0–30	4·98	27·7		9·2	63·1
	30–60	5·20	45·2		4·0	50·8
	60–90	5·21	57·4		1·9	40·7
	90–120	5·10	55·1		—	44·9
Ujfehértó, 312	0–30	5·42	2·2	12·9	27·9	57·0
	30–60	3·97	2·5	9·1	46·3	42·9
	60–90	12·63	0·9	9·2	12·0	77·9
Püspökladány, 398 ..	0–5	19·74	5·6	13·2	3·4	77·8
	5–10	21·67	2·3	5·5	2·1	90·1
Békéscsaba, 5		39·20	42·4	19·7	0·7	37·2
Hortobágy		19·7	26·0	13·9	4·3	55·8

Experiments have shown that we may find genuine Na soils even among littoral salines.*

In the preceding section I have endeavoured to characterise more fully the three main types of absorbing complex known to us—viz., those of saturated Ca soils, of unsaturated H soils and of alkali Na soils.

If we wish to estimate the character of a soil we cannot afford to ignore the quantity and stability—or the factors governing the decomposition—of its absorbing complex. For the present, indeed, we have no reliable method of determining exactly the quantity of the absorbing complex, but the T-value of the complex—i.e., the absorbing

* See HISSINK, D. J.: Int. Mitt. Bodenk., Vol. XII. (1922), p. 81.

capacity of the soil—must be proportional to the quantity of the active part of the complex.

From what has been said in this chapter it is evident that the chemical composition of the absorbing—or humus-zeolite—complex is of great help in characterising soils. The instantaneous character of base exchange makes the cations the most reactive constituents of the soil's solid phase. *These are the constituents which practically determine and reflect the dynamic character of the soil.* STEBUTT makes the quantity and quality of the humus-zeolite complex the basis of the whole dynamic system of the soil, and classifies his types of soil formation accordingly. GEDROIZ's system is indeed to some extent different, but he too classifies the known soil types on the basis of the chemical composition of the absorbing complex.

4. Laws of Apolar and Polar Adsorption.

(*Contributed by* DR. JOHN DI GLERIA.)

From a colloid-chemical point of view we may distinguish between *apolar* and *polar* adsorption processes intervening between the solid and liquid phases. Adsorption is apolar when the adsorbent adsorbs whole molecules out of the solution. This category includes also the cases in which the adsorbent adsorbs the molecules of the solvent. On the surface of contact between two substances the conditions
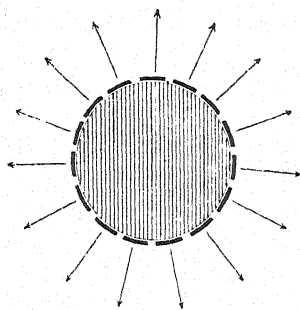
FIG 8.

differ entirely from those prevailing inside. These surface reactions were observed long ago and were called *adhesion*. Adhesion phenomena are due to the circumstance that, while in the interior of homogeneous substances the molecular forces are in equilibrium, on the surface part of those forces acts freely and operates outwards (in the direction of the second phase) as an attractive or repulsive force. Recent investigations show that the origin of these forces is the electric charge located on the surface of the atoms, the resultant force being bound inwards but able to assert itself freely in the direction of the second phase. Fig. 8 shows the sphere of energy of a particle electrically charged.

The arrows denote the lines of energy of the electric field. When a substance charged oppositely enters an electrically charged field of this kind, it remains bound on the surface, neutralising a part of the charge and reducing thereby the particle's sphere of energy. This kind of adsorption is called *polar adsorption*. The conditions are, however, different when the electric sphere of energy is entered only by electrically neutral molecules. In this case, since the neutral molecules have no free electric charge, the causes of the adsorption

are closely connected with the structure of the molecules—with what is called the *dipole moment* of the molecules. This form of adsorption —in which electrically neutral molecules are bound on the surface of electrically charged particles—is called *apolar adsorption*. In an
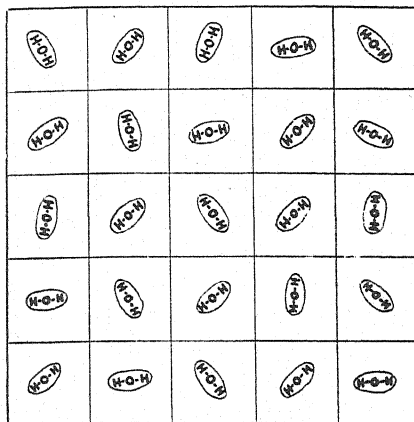
FIG. 9.
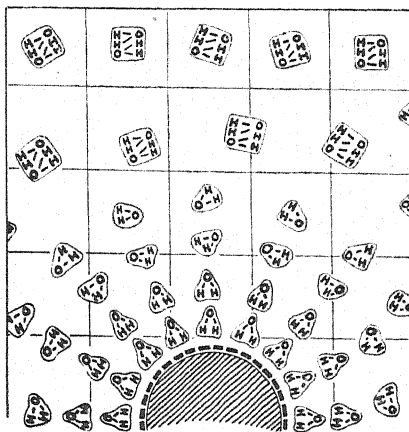
FIG. 10.

electric field not containing lines of electric energy the atoms of the water molecules are orientated as shown in Fig. 9.

The effect of the electric sphere of energy is, however, to deform
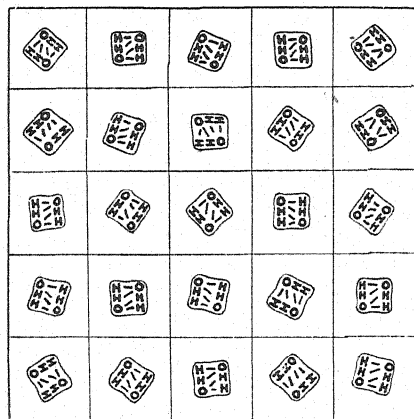
FIG. 11.
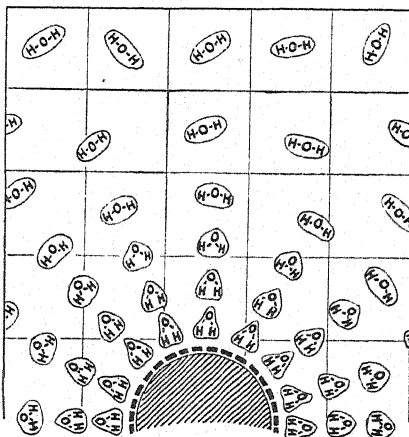
FIG. 12.

the water molecule, the two positively charged hydrogen atoms approaching one another and turning towards the surface of the negatively charged particle, while the molecule turns in the direction of the lines of energy, as shown in Fig. 10.

The deformation of the water molecules increases in direct proportion to the negative charge of the particle and in inverse proportion to the distance between the water molecule and the surface of the particle. The deformed molecule figures as a *dipole*, the measure of the attraction exercised upon it by the electrically charged particle depending upon the measure of the deformation. This is valid only when the soil takes up the water in the form of vapour. In this case the water may be regarded as *monomolecular* gas. The bimolecular structure of water in a liquid state is due to the dipole moment of the water molecules, which are so close to one another that the charge of the oxygen and hydrogen atoms of one molecule affects the other, the result being that instead of the monomolecular H-O-H arrangement supposed to exist in vapour the water assumes a bimolecular form as follows—

$$\begin{matrix} H & \diagdown & \\ & & O \\ H & \diagup & \\ & O & \diagdown H \\ & & \diagup H \end{matrix}$$
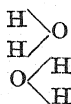
and the molecule figures as dipole. Two dipoles with opposing poles adjacent form a double molecule. Water in the liquid state consists of double molecules, the probable arrangement of which in a field not charged electrically is shown in Figs. 11 and 12.

Conditions are different, however, when an electrically charged particle enters water in a liquid state. For in that case the charge of the particle produces a denser and more compact water shell round the particle, the probable structure of this shell being shown in Fig. 12. The apolar adsorption of dissolved materials in dilute solution may be calculated from the empirical formula first employed by BOEDECKER,[*] —viz.,

$$x = k \times a^n,$$

where x denotes the quantity of matter actually adsorbed by 1 gramme of adsorbent, a the initial concentration of the adsorptive, k and n being constants. According to the above equation there is a logarithmic correlation between the initial concentration of the adsorptive and the quantity adsorbed. Later, FREUNDLICH[†] modified the equation, replacing the initial concentration of the adsorptive by the concentration in a state of equilibrium. FREUNDLICH's formula is as follows:

$$x = kc\overset{1}{v},$$

x denoting the quantity of the adsorbed material and c the equilibrium

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[*] See BOEDECKER, C.: Journ. f. Landw., Vol. VII. (1859), p. 49.

[†] See FREUNDLICH, H.: " Kapillarchemie," 2nd Ed. (1909), Dresden and Leipzig (Th. Steinkopff).

concentration of the adsorptive, k and $\dfrac{1}{p}$ being constants. In connection with apolar adsorption—in addition to the logarithmic isotherm referred to above—the two following isotherms are also in use. WOLFF's empirical isotherm is as follows:*

$$x = k_1 + \frac{k_2\,c}{k_3 + c},$$

x denoting the quantity of adsorbed material, c the equilibrium concentration of the adsorptive, k_1, k_2 and k_3 being constants.

The formula of LANGMUIR† is the following:

$$x = \frac{c \times \alpha}{1 + \beta \times c},$$

x denoting the quantity of adsorbed material and c the equilibrium concentration of the adsorptive, α and β being constants. With apolar adsorption we do not always get a maximum, in which case the values obtained are far more in keeping with the FREUNDLICH than with the LANGMUIR adsorption isotherm. Apolar adsorption processes are phenomena similar to reversible additive chemical processes. Table XXXII. shows the $Ba(OH)_2$ adsorption of carbo raffin (active carbon).

TABLE XXXII

Milligramme Equivalents of Ba(OH)₂ found in Solution after Adsorption.	Adsorbed Ba(OH)₂ in Milligramme Equivalents.		
	Found by Experiment.	Calculated by—	
		Freundlich's Formula.	Langmuir's Formula.
0·005	9·9	10·02	10·11
0·250	15·0	14·48	15·98
0·695	16·1	15·94	16·11
1·175	16·5	16·75	16·14
1·665	17·0	17·31	16·15

The quantity of adsorbed material has been calculated according to the formulæ of FREUNDLICH and LANGMUIR.‡   As will be seen,

* See WOLFF, G. O.: Landw. Ztg. f. Nord u. Mitteldeutschland, Berlin (1859).

† See LANGMUIR, I.: Journ. Amer. Chem. Soc., Vol. XXXVIII. (1916), p. 2221; Vol. XL. (1918), p. 1361.

‡ See DI GLERIA, J.: Verh. d. II. Komm. Int. Bodk. Ges., Budapest, Vol. A (1929), p. 59.

there is a fair agreement between the values actually found and the calculated values.

Apolar adsorption is caused by the unbalanced molecular energy acting on the surface. The dimensions of the sheaths of the apolarly adsorbed molecules may vary. These sheaths—the concentration of which differs from that of the main part of the solution—are called the *lyosphere*. The structure of this lyosphere varies according to the properties of the adsorbent. The degree of the adsorption of the *solvate* layer—in the case of water the *hydrate* layer—by the adsorbent depends upon the composition of the latter. In the case of the so-called *emulsoid* colloids the *solvate* (hydrate) layer acts as a sheath surrounding the colloid particle, impenetrable by the solute molecules or ions. On the other hand, in the case of the so-called *suspensoid colloids* the *solvate* (hydrate) layer is not so dense, for the solute molecules or ions are able to pass through it. To this difference in structure of the solvate layer are due the peculiarities which differentiate the *emulsoids* or *reversible colloids* from the suspensoids or *irreversible colloids*. The emulsoid colloids are also called *solvatocratic* (hydrocratic) or *lyophile* (hydrophile), the suspensoid colloids *electrocratic* or *lyophobe* (hydrophobe). These terms mean that in the case of emulsoid colloids, where the colloidal character is determined by the solvate layer, the particles show outside either no electric charge at all or only a very slight one and are not coagulated by the action of electrolytes. On the other hand, in the case of suspensoid colloids, where the colloidal character is determined by the electric charge of the particle, the particles are readily coagulated by the action of electrolytes. In the case of emulsoid colloids the charge of the particles is latent, but by warming or adding pure alcohol the structure of the solvate layer is loosened, the colloids then coagulating irreversibly on adding electrolytes. The transformation of the solvate layer converts the emulsoids into suspensoids, the nature of the colloids depending upon the electric charge on the surface of the particle. From what has been said it will be seen that there is no difference in principle between emulsoids and suspensoids; the differences apparent at ordinary temperature are only the results of differences in structure of the solvate layer.

In soils we find both suspensoids sensitive to electrolytes, such as aluminium hydroxide, ferric hydroxide and silicic acid, and hydrated emulsoids, such as humus. All the processes taking place during soil formation—e.g., the movement and accumulation in the several horizons of silicic acid, aluminium hydroxide, ferric hydroxide and humus—can be explained as due to the colloidal condition and peculiarities of these materials.

By *polar adsorption* we mean that kind of adsorption in which not whole molecules but electrically charged ions are adsorbed; or rather, where oppositely charged ions are present, and one is more adsorbed than the other. Since the law of electric neutrality demands the

replacing of the adsorbed ion by another ion, in polar adsorption an ion equivalent to the ion adsorbed from the surface of the adsorbent must pass into the solution, for which reason *polar adsorption* is also called *exchange adsorption*.

When no exchangeable ion is present on the surface of the adsorbent, one will be released by secondary chemical reaction from the medium itself. For instance, if we mix neutral solutions of sodium sulphate and barium chloride in different quantities, the solution resulting is either alkaline or acid according to whether the sodium sulphate or the barium chloride is in excess, the solution resulting when the quantities of both are equivalent being neutral. The explanation of this phenomenon is that with an excess of electrolytes the electrically unbalanced barium or sulphate ions present on the surface of the barium sulphate precipitate adsorb from the solution that ion which helps them to form a less soluble compound. With an excess of sodium sulphate the positively charged barium ions on the surface of the precipitate adsorb the negatively charged sulphate ions contained in the solution. As a consequence of the adsorption, sodium ions equivalent to the adsorbed sulphate ions react with water and set free an equivalent quantity of hydroxyl ions, resulting in the liberation of an equivalent amount of hydrogen ions. The hydrogen ions thus set free are adsorbed by the sulphate ions present on the surface of the precipitate. Thus the solution becomes alkaline. With an excess of barium chloride the barium ions and the hydroxyl ions resulting from the secondary action are adsorbed on the surface of the particles, the solution being enriched by hydrogen and chloride ions equivalent to the adsorbed barium ions. In this case the reaction of the solution is acid. The processes of reaction are shown in the following equations:

$$\begin{array}{c}Ba\\SO_4\\Ba\\SO_4\end{array} + 2n Na^+ + n SO_4^{--} + 2n HOH \underset{\longleftarrow}{\overset{\longrightarrow}{}} \begin{array}{c|c}Ba & SO_4 \\ SO_4 & H \\ Ba & H \\ SO_4 & SO_4 \\ & H \\ & H\end{array} + 2n Na^+ + 2n OH^-$$

$$\begin{array}{c}Ba\\SO_4\\Ba\\SO_4\end{array} + n Ba^{++} + 2n Cl^- + 2n HOH \underset{\longleftarrow}{\overset{\longrightarrow}{}} \begin{array}{c|c}Ba & OH \\ SO_4 & OH \\ Ba & Ba \\ SO_4 & OH \\ & OH \\ & Ba\end{array} + 2n H^+ + 2n Cl^-$$
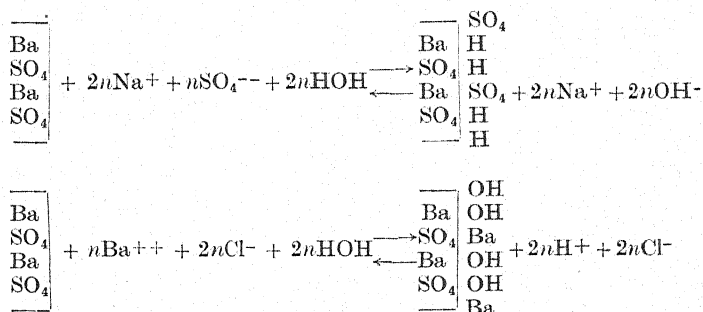
Polar adsorption is a process similar to a chemical interchange reaction; the course of the process may be expressed mathematically by the isotherms used in the case of apolar adsorption. It is usual to employ the following equations for polar adsorption—in addition to the apolar adsorption isotherms referred to above:

Wiegner isotherm:[*]

$$x = k \left(\frac{c}{x} \right)^{\frac{1}{p}}.$$

Rothmund-Kornfeld isotherm:[†]

$$\frac{x}{U-x} = k \left(\frac{c}{x} \right)^{\frac{1}{p}}.$$

Vageler isotherm:[‡]

$$x = \frac{Sa}{a+C}.$$

In the above equations x represents the quantity of the adsorbed ions, c the concentration in equivalents of the adsorbed ions, a the initial concentration of the adsorbed ions, k, $\frac{1}{p}$, S, U, and C being constants. Table XXXIII. contains data by Weiss,[§] who studied the validity of the most important adsorption isotherms in the case of base exchange with permutites:

TABLE XXXIII

Milligramme Equivalents of K per Litre added to NH$_4$ Permutite.	Milligramme Equivalents of Exchanged Ammonia calculated to 1 Gramme Permutite.				
	Found by Experiments.	Calculated by the Formula of—			
		Freundlich.	Wiegner.	Rothmund—Kornfeld.	Vageler.
20	1·153	1·311	1·324	1·353	1·182
40	1·602	1·516	1·523	1·608	1·584
200	2·105	1·791	1·789	1·901	2·027
1000	2·330	2·543	2·512	2·369	2·425

It will be seen that there is a satisfactory agreement between the empirical results and the calculated values. The isotherm of polar adsorption often leads to a maximum ending in a horizontal line,

[*] See Wiegner, G., and Jenny, H.: Kolloidchem. Beih., Vol. XXIII. (1927), p. 428.
[†] See Rothmund, V., and Kornfeld, G.: Zeitschrift f. anorg. u. allgem. Chem., Vol. CIII. (1918), p. 128; Vol. CVIII. (1919), p. 215; Vol. CXI. (1920), p. 76.
[‡] See Vageler, P., and Woltersdorf, J.: Zeitschr. Pflanz. Düng. Bodk., Part A, Vol. XV. (1930), p. 329.
[§] See Weiss, L.: " Der Kationenumtausch an Permutiten und seine Formulierung," Dissertation (Zürich, 1932).

a phenomenon observable also in heterogeneous chemical reactions. *This kind of polar adsorption is often called physico-chemical adsorption, and is analogous to the physico-chemical adsorption of the base exchange observable on permutites and zeolites.* In the case of heterogeneous reactions the reaction cannot exceed the stochiometrical laws. In certain cases of polar adsorption, too, we find isotherms expressing a stable saturation. The course of the latter is slower than that of apolar adsorption, for whereas apolar adsorption takes place instantaneously on the surface of the particles, in certain cases of polar adsorption the adsorbed ions may penetrate even into the interior of the adsorbent and may also exchange the ions in the interior of the particles. Phenomena of this kind occur in the case of natural crystalline zeolites and of permutites or artificial zeolites.

As already explained, polar adsorption is caused by the unbalanced electric sphere of energy of the ions present on the surface, that energy attracting the oppositely charged ions from the solution to the vicinity of the surface. The inner ion-shell of the particle is formed by the ions on the surface of, and in close contact with, the particle. The charge on these ions also determines the charge on the particle. Opposite to this inner ion-shell is the outer ion-shell consisting of oppositely charged ions which are less closely con-

Fig. 13.

nected to the particle. The exchange processes take place generally between the outer ion-shell and the ions of the solution. The particles are thus surrounded by *an electric double layer.* The particle and the inner ion-shell combined are called *micellar-ion,* the latter being spoken of *as micellar anion* or *micellar cation* according to the character of the electric charge on the inner ion-shell. The electric double layer of the particle may be regarded as a condenser, one part of the armature of which is provided by the inner ion-shell of the particle and the other by the outer ion-shell. Recent experiments have, however, shown that the outer ion-shell forms a diffuse lay consisting of several swarms of ions. In the inner part of the diffuse ion-layer are accumulated only the ions with charges opposite to that of the particle, while in the following layer we may find also ions with similar charges. The distribution of the ions changes gradually from the inner ion-shell of the particle outwards until we get the distribution shown in Fig. 13 above.
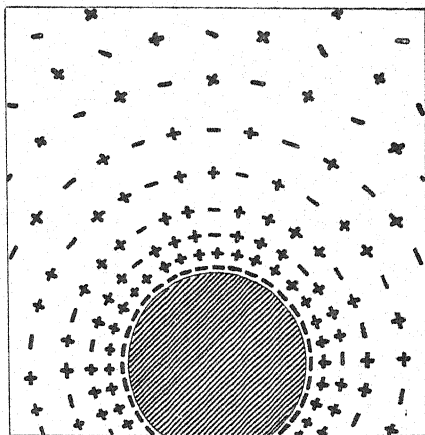
The diffuse outer ion-shell is in dynamic equilibrium with the solution. Where there are several kinds of ions in the outer ion-shell, their distribution between the shell and the solution depends partly on the concentration of the various ions and partly on the place occupied by them in the lyotrope series. In the case of colloidal particles possessing a special inner structure, the ions with the same electric charge as the outer ion-shell may be replaced inside the particles by the ions of the outer shell. This happens only where on the one hand ions with an electric charge similar to that on the outer shell can move freely in the crystal frame of the particles, and on the other hand the ions of the outer ion-shell have room in the crystal frame of the particles. This happens in the polar adsorption taking place in the case of crystalline zeolites and permutites. Recently soil scientists have assumed that the surface of a colloidal particle is not even, but undulating, with edges, sides and indentations, and the ions adsorbed on the edges and peaks are more easily exchangeable than those in the depressions. Thus it may happen, for instance, that notwithstanding its place in the lyotrope series the magnesium cation cannot exchange so easily as the calcium cation.*

In soil processes a very important rôle is played by polar adsorption. Thus the formation of alkali soils is, in the opinion of GEDROIZ† and SIGMOND,‡ due to the polar adsorption of sodium ions. To similar processes of polar adsorption are due also hydrogen and calcium soils; but, whereas in the case of alkali soils the concentration of the sodium ions has always been the determining factor, in the formation of hydrogen or calcium soils the peculiar place in the lyotrope series of hydrogen and calcium ions has determined the course of the reaction.

One of the causes responsible for the cessation of the colloidal state is the accumulation of the colloidal particles to form larger particles. This result may ensue either by crystallisation or by coagulation. In the former case the smaller crystalline particles are transformed into larger crystals, the result being that the original surface area disappears. In the latter case, on the other hand, the particles of the dispersion system coagulate into larger particles without the smaller particles losing their original surface area. The larger particles formed by coagulation are called the *coagulate*. Coagulation may take place either *reversibly* or *irreversibly*. In the former case the coagulate can be dispersed and changed into a colloidal solution by the action of the solvent. In the case of irreversible coagulation the coagulate cannot be changed by the action of the

* See WIEGNER, G.: Proc. III. Intern. Congr. Soil Sci., Vol. III. (1936), p. 5.

† See GEDROIZ, K. K.: " Der adsorbierende Bodenkomplex " (Th. Steinkopff, Dresden, Leipzig, 1929).

‡ See SIGMOND, A. A. J. DE: Proc. Papers I. Int. Congress Soil Sci., Vol. I. (1927), p. 330.

solvent into a colloidal solution, unless the dissolution is effected by the action of certain substances known as *peptisers*.

We shall first deal with those factors which ensure the maintenance of the colloidal state or the so-called *stability* of colloids.

Colloidal particles owe their existence to two factors. The first of these factors is the electric charge on the surface, which, if sufficiently strong, is able to prevent the coagulation of particles with a similar electric charge. The other factor is the apolarly adsorbed solvate or hydrate layer on the surface, which surrounds the particles like an elastic protecting sheath and prevents their coagulation. Both factors combine to ensure the stability of the colloidal particles. The stability of a particle is determined primarily by that factor which happens to be dominant.

In emulsoids the stability of the particles is ensured primarily by the solvate layer and in suspensoids by the electric charge on the particles. Fig. 14 shows that in the one case it is the solvate layer formed from the molecules of the apolarly adsorbed solvent that defines the character of the particle; while in the other case that character is determined by the polarly adsorbed diffuse ion-shell. The figure naturally shows ideal extreme cases, for in nature in the case of solvato-cratic colloids we may find not only apolar molecular adsorption but also to some extent polar

Fig. 14.

ion adsorption. Similarly, in the case of electrocratic colloids we may find some apolar adsorption in addition to polar adsorption.
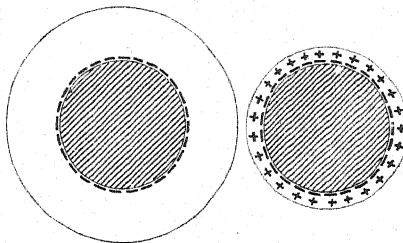
The assumption that in soils the hydration of the particles is merely the result of hydration of polarly adsorbed ions is incorrect. It cannot be correct, if only because the colloids occurring in soils form a transition between electrocratic and solvatocratic colloids. In these colloids both factors play an approximately equivalent part in ensuring the stability of the particles. Soils also contain a typical emulsoid colloid—humus—the stability of which is ensured by the apolar adsorption of water. From what has been said it will be seen, therefore, that the stability of the colloidal particles is ensured by the solvate layer surrounding them or by the charge on the particles themselves, both contributing to prevent the coagulation which might otherwise be induced by the collisions resulting from what is known as *the Brownian movement*. Thus no colloidal system can coagulate until the particles have lost their solvate layers and their electric charges. This explains reversible coagulation: in this case all that disappears is the solvate layer of the particles, the electric charge on the other hand remaining and enabling the particles on contact

with the solvent to reabsorb the solvate layer and thereby to change
back again into colloidal solution. If, on the other hand, in addition
to eliminating the solvate layer, we also neutralise the electric charge
on the particles by adding electrolytes, irreversible coagulation will
take place. The limiting potential beyond which the particles cannot
coagulate at all is called the *critical potential* of the particles. In
the case of electrocratic coagulation the rapidity of coagulation
depends upon the electrolyte's concentration and position in the
lyotrope series. Above a certain electrolyte concentration the charge
on the particle is completely neutralised, and in this case all colliding
particles coagulate. SMOLUCHOWSKY* calls the coagulation ensuing
under these circumstances *quick* coagulation; its rapidity may be
calculated with the aid of the following equation:

$$\delta = \frac{\delta_o}{1 + 4\pi \times A_1 D_\rho \delta_o t}.$$

In the above equation δ_o denotes the number of particles before
coagulation, δ the number of particles at time t, A_1 the active radius
of the particle, D_ρ the diffusion constant of the particles and t the time
that has elapsed since the addition of the electrolyte. SMOLUCHOWSKY's
formula refers to monodispersed systems; but WIEGNER and MÜLLER†
have applied it also to polydispersed systems. The electrocratic
colloids may to some extent be protected against the coagulating
effect of electrolytes by the addition of solvatocratic colloids. For
that reason the *solvatocratic colloids are sometimes called protective
colloids*. In soils humus functions as a protective colloid; its effect
has been dealt with exhaustively by AARNIO.‡

In connection with irreversible coagulation we must also consider
the opposite process—*peptisation*—as a phenomenon which plays an
important rôle in soils. By peptisation is meant the process which
by the addition of certain substances reconverts an electrocratic
coagulate into a colloidal solution. The main point in this process
is that it raises the potential of the coagulated particles above the
critical potential. This happens either as the result of an addition
of electrolytes or of a reduction in the electrolyte concentration.
In the former case an ion exchange or polar ion adsorption increases
the charge on the particles, while in the latter case the leaching out
of the electrolytes removes from the system the electrolytes which
cause coagulation, and the particles recover their original charge.
Both cases occur in soils. The first occurs when a good steppe soil
is converted into an alkali soil by the action of alkali salts. We may,
indeed, regard steppe soils as coagulates resulting from the effect of

* See SMOLUCHOWSKY, M.: Physikalische Zeitschr., Vol. XVII. (1916),
p. 557; and Zeitschr. f. Phys. Chem., Vol. XCII. (1917), p. 129.
† See WIEGNER, G., and MÜLLER, H.: Kolloid Zeitschr., Vol. XXXVIII.
(1926), p. 1.
‡ See AARNIO, B.: Int. Mittlg. f. Bodenk., Vol. III. (1913), p. 131.

calcium ions, which have coagulated the original particles into larger particles with a crumbly structure. The effect of alkali salts is to replace the calcium ions on the surfaces of the particles by sodium ions, which increase the charge on the particles; this is accompanied by increased dispersion. Many cases of peptisation caused by leaching are also to be found in the irrigation of saline soils. It often happens that the leaching of salts results in an increase in dispersion sufficient to produce impermeability in an originally well-drained soil.

5. Characteristics of the Water Extract of Soils.

Solid, liquid and gaseous materials are found mixed in soils and interact not only physically but chemically also. The so-called natural soil solution is the ultimate medium in which all chemical reactions take place in the soil; it is where the chemical dynamics of soil assert themselves. Reactions which take place on the surface of the insoluble solid particles occur only at points which come in contact with the soil solution (liquid phase of the soil), and the gaseous constituents are inert unless absorbed or dissolved by the soil solution. In this sense we are justified in calling the soil solution the most active part of the soil and the dissolved elements the most active constituents.

The simple salts of soils may be grouped according to three grades of solubility.

1. *Readily Soluble Salts.*—Such are the chlorides and nitrates, especially of Na, K, Ca and Mg. Of the sulphates those of Na, K and Mg, and of normal carbonates those of Na and K are readily soluble. The bicarbonates of the above-mentioned four cations are also easily soluble. $Mg(HCO_3)_2$, differs from $Ca(HCO_3)_2$, in that the former is a barely stable compound, breaking up easily into $MgCO_3$ and CO_2, and precipitating as a normal carbonate. $Ca(HCO_3)_2$, on the other hand, is fairly stable even in quite concentrated solutions. The bicarbonates of the alkali cations are much less stable in concentrated solution, changing into normal carbonates, which are, however, water-soluble. The latter solutions are alkaline owing to the hydrolysis of the normal carbonates, as shown in the following equation for sodium carbonate:

$$Na_2CO_3 + 2HOH \rightleftharpoons 2NaOH + CO_2 + H_2O.$$

We may include also ammonium salts among the readily soluble salts of soils, their proportion being, however, usually very insignificant.

2. *A salt of medium solubility* is gypsum, very frequent in soils of dry climate and sometimes found in a considerable percentage.

3. *Slightly soluble salts* found in soils are the normal carbonates of Ca and Mg and the phosphates of Ca, Fe and Al. We might also include here the unweathered silicates and the absorbing or humus-zeolite complex. These are all only slightly soluble in water, but

they are generally not regarded as simple salts of the soil but as constituents of complex chemical composition.

About the solubility of the above-mentioned simple salts we have data enough in literature. Some interesting figures are shown in Table XXXIV.

TABLE XXXIV

GRAMMES OF SALTS DISSOLVED IN 100 GRAMMES OF SOLUTION

	0° C.	10° C.	20° C.	25° C.	30° C.	40° C.
$(NH_4)NO_3$	54·2	—	—	68·2	70·8	—
KNO_3	11·5	17·7	24·1	—	31·6	39·2
$NaNO_3$	42·2	44·6	46·8	—	49·0	51·2
$Mg(NO_3)_2$	40·0	—	—	—	—	45·9
$Ca(NO_3)_2$	48·2	—	(18°) 54·8	—	—	(42·4°) 69·5
$(NH_4)Cl$	22·9	25·0	27·1	—	29·3	31·4
KCl	21·9	20·8	25·6	25·78	27·2	28·7
$NaCl$	26·34	26·30	26·38	—	26·50	26·65
$MgCl_2$	34·6	34·9	35·3	—	—	36·5
$CaCl_2$	37·3	39·4	42·7	—	—	53·5
$(NH_4)_2SO_4$	41·4	42·2	43·0	—	43·8	44·8
K_2SO_4	6·89	8·50	10·07	10·75	11·50	13·17
Na_2SO_4	4·22	8·24	16·00	21·90	29·00	32·50
$MgSO_4$	—	23·6	26·2	26·8	29·00	31·3

CAMERON* has investigated the changes in the solubility of salts when two or three are dissolved in the same solution. The equilibrium of the carbonates and bicarbonates is of special pedological interest, for, as soil solutions contain varying amounts of carbonic acid, there is always a possibility of the formation of bicarbonates in soil. Though it is often impossible to estimate the true proportion of the various carbonates in the soil solution, we have proof that sometimes only bicarbonates (HCO_3 anions) are present in the soil solution, while in other cases a certain amount of normal carbonate (CO_3 anions) is present also.

The changes in equilibrium between normal carbonate and bicarbonate of sodium are of special pedological interest. We may say in general that by raising the temperature to 100° C. the proportion of the sodium bicarbonate gradually decreases with a corresponding increase of the normal carbonate. At 100° C. in a boiling solution all bicarbonates of sodium are changed into normal salts.

If the amount of Na in 1 litre of water is less than 9 grammes the proportion of bicarbonates increases gradually with increase of dilu-

* See CAMERON, F. K.: U.S. Dept. Agr. Div. Soils, Bull. 17 (1901); Rep. Field Op. Div. Soils (1900), p. 423.

tion; at the stage called infinite dilution only bicarbonates are present. The pedological significance of this fact is that it becomes possible to change the normal sodium carbonate into bicarbonate by extreme dilution of the soil solution. If the amount of Na in 1 litre of water is exactly 9 grammes at a temperature of 25° C., the balance of the two salts is as follows: 63 per cent. of Na is in solution as normal carbonate and 37 per cent. as bicarbonate.

The proportion of the former salt increases to 65 per cent., when the amount of dissolved Na per litre increases to 45 grammes. When the amount of Na dissolved in 1 litre of water is 2·9 grammes, the respective proportions of Na contained in the two salts are the same. It is quite natural that these proportions are shifted when we take into consideration the relative amounts of the two sodium carbonates. For instance, the proportion of both salts is about the same when their total amount is 21 grammes per litre, so that in a solution of approximately 2 per cent. we have about 1 per cent. normal carbonate and 1 per cent. bicarbonate of sodium. If, however, the concentration of the solution amounts to 56·5 grammes per litre (about 6 per cent. solution), we find 30 g. Na_2CO_3 and 26·5 g. $Na(HCO_3)_2$ dissolved in 1 litre of water—*i.e.*, the proportion of the normal carbonate has increased to 53 per cent. We see from these figures that with increasing concentration the proportion of normal carbonate increases. It is, however, important from a pedological point of view to note that in all cases below a temperature of 100° C. the water solution cannot be exclusively one of normal sodium carbonate, so that the salt crust of sodium carbonate always contains some bicarbonate.

The behaviour of potassium salts is practically the same as that of sodium salts, only the deviations are somewhat smaller. Their rôle in soils is far less significant because the bulk of the potassium in soils is absorbed.

More interest attaches to the carbonates of *Ca* and *Mg*. According to SCHLÖSING, in 1 litre of CO_2-free distilled water at a temperature of 16° C., only 0·0131 g. $CaCO_3$ can be dissolved, and according to TREADWELL and REUTER under pressure of 760 mm. at 16° C. 1·156 g. $CaCO_3$ are dissolved in an atmosphere of carbonic acid. In water saturated with carbonic acid 0·0746 g. is soluble at 16° C. CAMERON's experiments showed that in ordinary soil solutions only calcium bicarbonate (which is fairly stable at normal temperature) but not normal calcium carbonate is dissolved. In this respect Mg differs very distinctly from Ca. For the normal carbonate of Mg is more easily soluble in water and its bicarbonate less stable than the corresponding salts of Ca. CAMERON concluded that in normal air there is equilibrium with 50 per cent. of normal carbonate and 50 per cent. of bicarbonate, *hence waters rich in carbonate of magnesium, tested with phenolphthalein, show alkaline reactions.* Normal calcium carbonate itself is also slightly alkaline, but, being easily transformable into bicarbonate, the alkaline reaction disappears very quickly. Conse-

quently alkalinity in soil solutions may be due not only to normal alkali carbonates but sometimes to normal magnesium carbonate.

From a pedological point of view it is interesting to note that sodium salts produce a considerable change in the solubility of normal calcium carbonate, due to chemical interaction. CAMERON added excess $CaCO_3$ to NaCl solutions of various concentrations, passing air through the solution during twenty-seven days in order to obtain full equilibrium. In all cases the solutions contained only bicarbonates. With distilled water only 0·1046 g. $Ca(HCO_3)_2$ ($=0·064$ g. $CaCO_3$) was dissolved. When 9·7 g. NaCl (roughly 1 per cent. solution) acted on $CaCO_3$ the solution contained 0·177 g. $Ca(HCO_3)_2$ ($=0·1094$ g. $CaCO_3$), and with increase in concentration of NaCl in the solution, the proportion of dissolved $Ca(HCO_3)_2$ increased until the concentration of the sodium chloride reached about 5 per cent. With further increase of the NaCl concentration the solubility of the $CaCO_3$ decreased gradually.

Sodium sulphate exercises an even greater effect than sodium chloride on the solubility of $CaCO_3$. In a solution of 5 g. Na_2SO_4 CAMERON found 0·173 g. $Ca(HCO_3)_2$ dissolved, and in a solution of 35 g. Na_2SO_4 per litre 0·325 g. $Ca(HCO_3)_2$, 8 per cent. of the latter being dissolved as normal carbonate. With 160 g. Na_2SO_4 per litre 0·45 g. $Ca(HCO_3)_2$ was dissolved, the solution containing 18 per cent. of normal carbonate. It seems also that further increase of Na_2SO_4 leads to an increase of solubility of $CaCO_3$, there being no decrease above a fixed concentration.

It must be noted, however, that in all the above cases the increase of solubility of $CaCO_3$ is not due to a simple physical dissolution of $CaCO_3$ molecules, but is the result of a chemical reaction between $CaCO_3$ and NaCl or Na_2SO_4. The same is true when $MgCO_3$ is present in the soil together with NaCl or Na_2SO_4. The $MgCO_3$, however, being more soluble than $CaCO_3$, the chemical process is more active.

All these reactions are pedologically very significant, leading as they do to the formation of soda in soils. These reactions may be represented by the two following equations:

$$R^{II}(HCO_3)_2 + 2R^{I}Cl = 2R^{I}HCO_3 + R^{II}Cl_2,$$

and

$$R^{II}(HCO_3)_2 + R^{I}_2SO_4 = 2R^{I}HCO_3 + R^{II}SO_4.$$
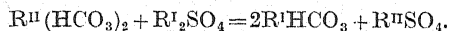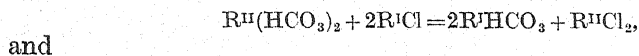
R^{II} means bivalent Ca or Mg, and R^{I} monovalent Na or K. Both reactions are reversible—i.e., if carbonic acid in the soil solution is in excess the balance of the reversible reactions is shifted to the right; if, however, SO_4 or Cl anions are in excess as compared with the HCO_3 anions the balance may turn back towards the left. It is easy to understand that the $NaHCO_3$ formed according to the above reactions of CAMERON may easily change into Na_2CO_3, especially when the soil

is becoming drier. This is the basis of HILGARD's theory of *soda formation in alkali soils*.

There is, however, another possibility of soda formation in alkali soils, where the absorbing complex (T^m) is partly saturated with sodium, and the soil solution is rich in carbonic acid (H_2CO_3). The interchange takes place as follows:

$$T^m \overset{-x}{\underset{-Na}{-}} Na + H_2CO_3 = T^m \overset{-x}{\underset{-H}{-}} H + Na_2CO_3.$$
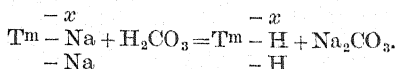
According to GEDROIZ, KELLEY and others this is the only process resulting in the formation of any considerable quantity of soda. In my opinion both theories are right and soda may be formed in soils in both ways. The difference between the two possibilities is that whereas according to GEDROIZ's theory soda formation can take place only in alkali soils from which the other alkali salts ($NaCl$ or Na_2SO_4) have already been leached, according to HILGARD's theory the presence of abundant $NaCl$ or Na_2SO_4 makes soda formation more active if combined with an excess of carbonic acid. GEDROIZ found that in Russian alkali soils sodium carbonate had accumulated only in soils in which the proportion of other sodium salts was insignificant. In Hungarian alkali soils, however, I have found just the opposite. Sodium carbonate has accumulated very often in alkali soils rich in other alkali salts and in $CaCO_3$. Even in those cases where the bulk of the water-soluble salts consists almost entirely of Na_2CO_3 and $NaHCO_3$ the soil is always very rich in $CaCO_3$. It seems, therefore, that in the Hungarian alkali soils the formation of soda takes place mostly according to the above reactions between $CaCO_3$ and $NaCl$ or Na_2SO_4. In leached and degraded alkali soils, however, it is possible that slight amounts of soda may be formed according to GEDROIZ's theory.

A fact of interest to the pedologist is that normal sodium carbonate decreases the solubility of $CaCO_3$. This is evidenced by numerous natural phenomena and laboratory experiments. I have found, for instance, that in the stagnant water and salty lakes in the areas of the Hungarian soda soils, which are also very rich in $CaCO_3$ (about 10-30 per cent.) the water itself is practically devoid of Ca, containing only Na_2CO_3 and $NaHCO_3$.*

DR. JOHN DI GLÉRIA, working in my laboratory, tested the solubility of $CaCO_3$ in solutions of various reactions, and found that an increase in pH value is accompanied by a decrease in dissolved $CaCO_3$. The solutions under pH 7 were acidified by carbonic acid, while those above pH 7 were alkalinised by adding to the water gradually more and more Na_2CO_3. Some of his results are included in Table XXXV.

This has been corroborated by analyses of a Hungarian black steppe soil at Gyula in which the proportion of $CaCO_3$ gradually increased

* See SIGMOND, A. A. J. DE: "Hungarian Alkali Soils and Methods of their Reclamation," Univ. of California Printing Office, Berkeley, Cal., 1927, pp. 108-9.

with the depth, whereas in the water extract of the various soil horizons dissolved Ca decreased with the depth owing to the increase of pH of the soil horizons. The relevant analytical results obtained in my laboratory by DR. LADISLAUS KOTZMANN are included in Table XXXVI.

TABLE XXXV

pH value of the solutions	6·21	6·50	7·12	7·85	8·60	9·20	10·12
Dissolved $CaCO_3$ (mg. in 1 litre solution)	965	720	356	135	54	41	18

TABLE XXXVI

$CaCO_3$ Per Cent.	pH.	CaO (mg. dissolved by 1 Litre Water from 100 Grammes Soil.)
1·69	8·88	25·3
5·25	9·00	21·6
7·95	9·00	23·9
10·08	9·15	10·5
13·12	9·24	7·1

Finally the solubility of gypsum ($CaSO_4.2H_2O$) is of some pedological significance. Confining ourselves to the cases where the solubility of gypsum is influenced by sodium salts, we find that in general $NaCl$ and $MgCl_2$ increase, while Na_2SO_4 and $CaCl_2$ decrease the solubility. In these cases, too, the increase of solubility of the gypsum is combined with chemical reactions. In the case of $NaCl$, for instance, the chemical reaction may be formulated as follows:

$$CaSO_4 + 2NaCl = Na_2SO_4 + CaCl_2.$$

In the case of Na_2CO_3, however, the reaction leads to the disappearance of the soda in soils—a circumstance of great importance in alkali reclamation—as is shown by the following equation:

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$
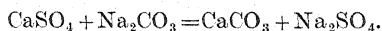
This is the same reaction (only in the opposite sense) as we have already discussed when dealing with soda formation in soils.

Having described the solubility conditions of the pedologically significant simple salts, let us now consider the solubility of the absorbed cations and of those which are still present in the form of original minerals. GEDROIZ has shown that if we treat non-saline soils with distilled water saturated with the carbonic acid of the atmosphere, the concentration of the water extract of the soil increases with a decrease of the ratio of soil to water, but not in the same proportion as that ratio would lead us to expect.* If the water dissolved only readily soluble salts, the amounts dissolved would be constant;

* See GEDROIZ, K. K.: "Chemische Bodenanalyse." Gebr. Borntraeger, Berlin, 1926, p. 149.

and by varying the ratio of soil and water we should find that dilution changed the concentration in exact proportion to the change in the ratio of soil and water. On the other hand, if the water dissolved only the cations of the absorbing complex the concentration of the solution would to a certain extent remain constant. However, in the case of soils this is not so, showing that the water dissolves not only water-soluble salts but also part of the absorbed cations. However, the soil extracts used in laboratories are always much more dilute than, and their composition probably different from, natural soil solutions. Nevertheless, it is sometimes very useful to know the chemical composition of water extracts of soils. Until recently water extracts of soils were usually analysed in respect of their plant-food content. This procedure gives no instructive information for soil characterisation, for which purpose we must know the chief cations (Ca, Mg, K and Na) and anions (Cl, SO_4, HCO_3 and CO_3), possibly the total dry residue and the loss on ignition. Tables XXXVII., XXXVIII., and XXXIX. show typical figures.

Table XXXVII. gives the bases dissolved by 1 litre of distilled water after shaking for two minutes at laboratory temperature. The analyses were made by Dr. L. Kotzmann in my laboratory by Gedroiz's method. The Table also includes the exchangeable bases, to show that there is no general connection between the absorbed and the water-soluble bases, owing to the fact that each of the soils represents a distinct soil type. When, however, we try to discover some characteristics of the individual soil types, the water-soluble bases are very instructive. Thus in soils 1 to 5—at least in their upper horizons—CaO is the prevailing base in the water extracts, whereas in soil 6 CaO is the least significant. This is far better illustrated in Table XXXVIII., which gives the equivalent percentages of cations and anions.

The contrast in the CaO is due to the fact that soils 1 to 5 are derived from parent materials rich in $CaCO_3$ (see Table XXXIX.), while in the case of soil 6 the parent rock was poor in calcium and the acid leaching processes have made the lack of calcium even more conspicuous.

The figures for Na_2O are very instructive too. In the black steppe soil its amount increases considerably with the depth. This phenomenon is not confined to this particular profile, as we have investigated several others and have found it to be common in the Hungarian black steppe soils.

In the case of the degraded black steppe soil the increase of Na_2O, though still evident, is far less so. Owing to the more acid leaching the black meadow soil does not show similar tendencies. The Spanish soils also seem to be leached out sufficiently to prevent any accumulation of sodium in the deeper horizons.

In the water solutions we can determine only the ions, and we know nothing about their original combinations. Water, however, dissolves primarily the most easily soluble salts, the less soluble salts

TABLE XXXVII

Calculated to 100 Grammes Soil Dried at 105° C.

Description of Soil and Depth of Soil Horizons.		Milligrammes Dissolved in Water.				Milligrammes of Bases Exchanged.			
	Cm.	CaO	MgO	K_2O	Na_2O	CaO	MgO	K_2O	Na_2O
1. Black steppe soil of Mező-hegyes.	0-3	25.8	3.0	13.8	10.2	522.8	48.2	7.8	9.8
	30-60	28.6	3.5	9.1	34.2	338.8	61.5	12.5	15.2
	60-90	32.5	9.1	6.7	53.2	216.1	141.3	14.9	16.3
	90-120	31.3	17.9	4.4	87.4	109.8	221.9	19.2	41.2
	120-150	28.4	15.2	7.4	95.6	54.5	108.2	20.2	39.2
2. Degraded steppe soil of Hajdudorog.	0-30	12.8	2.8	6.2	9.7	421.1	52.8	20.0	15.6
	30-60	18.6	4.6	4.3	10.3	526.4	56.0	18.4	20.4
	60-90	27.4	3.7	4.8	12.8	479.4	54.4	15.6	20.8
	90-120	22.9	4.1	5.1	16.1	375.2	57.6	15.2	36.4
	120-150	10.7	6.9	3.9	30.2	89.6	100.8	13.2	108.8
3. Black meadow clay soil of Mezőberéuy.	0-30	26.2	3.2	5.2	3.8	999.0	110.4	49.6	32.4
	30-60	30.5	3.1	4.9	6.3	875.8	90.4	30.0	26.0
	60-90	19.6	0.9	5.7	9.2	681.0	107.2	25.5	33.2
	90-120	22.4	1.3	6.0	8.6	645.1	124.8	22.4	32.8
	120-150	23.6	1.3	6.9	10.3	312.7	97.3	10.9	26.3
4. Rendzina Ct-1 of Spain.	Horizon. I.	31.7	9.4	7.8	10.8	931.6	22.8	19.4	14.8
	II.	24.8	5.6	2.5	14.8	450.0	25.0	13.9	5.2
	III.	23.1	4.2	4.0	10.1	447.4	20.0	16.8	10.3
5. Red soil Hc-2 of Spain.	I.	24.1	0.8	2.9	8.1	614.3	2.4	29.5	15.2
	II.	22.3	1.6	5.1	10.4	407.7	15.4	2.1	2.4
	III.	27.4	1.0	5.9	10.6	257.0	23.6	2.1	22.2
	IV.	14.3	1.8	3.6	14.7	113.4	2.6	3.6	2.5
6. Forest soil on granite Md-52 of Spain.	S.	2.9	15.0	5.2	5.6	308.6	15.7	22.4	20.4
	I.	1.7	17.4	6.1	6.9	182.0	16.5	16.7	15.5
	II.	1.3	16.5	3.1	8.6	399.6	28.6	10.1	22.2
	III.	0.6	15.3	2.9	11.3	160.7	—	5.3	10.2

TABLE XXXVIII

Percentage of Equivalents of Cations and Anions dissolved in Water, calculated to the Sum of Cation Equivalent as 100.

No. of the Soil.	Depth. Cm.	Ca	Mg	K	Na	Cl	SO₄	HCO₃	CO₃	Deficit of the Anions.
1.	0-30	54·12	8·82	17·65	19·41	7·64	6·47	73·52	—	− 12·37
	30-60	41·13	6·85	7·66	44·36	7·66	14·92	39·52	—	− 37·90
	60-90	33·43	12·97	4·03	49·57	15·27	13·83	28·35	—	− 42·37
	90-120	22·72	18·05	2·03	57·20	12·17	43·00	29·41	—	− 15·32
	120-150	20·20	15·00	3·20	61·60	20·60	52·20	14·40	—	− 12·80
2.	0-30	44·23	13·46	12·50	29·81	—	3·84	73·08	—	− 23·08
	30-60	50·38	17·56	6·87	25·19	—	12·97	73·18	—	− 13·75
	60-90	58·68	10·78	5·99	24·55	4·79	20·36	59·28	—	− 15·57
	90-120	49·70	12·12	6·67	31·51	10·91	40·61	49·70	—	—
	120-150	21·47	19·21	4·52	54·80	18·08	42·37	40·68	—	—
3.	0-30	65·73	18·18	7·69	8·40	—	39·16	12·59	—	− 48·25
	30-60	72·85	9·93	3·97	13·25	—	29·80	9·27	—	− 60·93
	60-90	60·34	3·46	10·34	25·87	—	55·17	17·24	—	− 27·59
	90-120	62·99	4·72	10·24	22·05	—	59·06	17·32	—	− 23·62
	120-150	60·87	4·35	10·87	23·91	—	72·46	14·92	—	− 13·05
4.	I.	53·3	22·2	8·0	16·5	12·74	—	71·22	—	− 16·04
	II.	52·4	16·5	2·9	28·2	8·23	2·35	57·64	—	− 31·78
	III.	56·9	14·6	5·6	22·9	11·11	1·39	64·58	—	− 22·92
5.	I.	70·5	3·3	4·9	21·3	4·92	10·65	62·29	—	− 22·14
	II.	60·1	6·0	8·3	25·6	3·76	12·03	69·92	—	− 14·29
	III.	65·9	3·3	8·0	22·8	13·42	29·53	44·97	—	− 12·08
	IV.	44·3	7·8	7·0	40·9	6·96	19·13	55·65	—	− 18·26
6.	S.	8·8	65·6	9·7	15·9	7·96	18·58	27·43	—	− 46·03
	I.	4·7	67·8	10·2	17·3	7·87	43·31	22·05	—	− 26·77
	II.	4·1	67·2	5·7	23·0	6·55	25·41	17·21	—	− 50·83
	III.	1·7	63·3	5·0	30·0	11·66	33·33	35·83	—	− 19·18

being only partly dissolved, according to the general laws of solutions. Consequently by ascertaining the proportions of the various anions we can with some probability guess what salts were originally present in the soil itself. There is no doubt that the chlorides and sulphates of the alkali cations are the first to be dissolved, and the concentration of these salts determines the rate of solution of the less soluble Mg and Ca salts. If the soil did not contain an absorbing complex, or the latter did not absorb alkali cations, which are more easily exchangeable than Ca and Mg, we might plausibly state that the dissolved Cl and SO_4 ions were combined primarily with the alkali cations, the rest of the SO_4 ions being combined with Mg; only in the presence of a considerable surplus of ions is gypsum dissolved. In this case again HCO_3 points to the presence primarily of $CaCO_3$, and only secondly of $MgCO_3$ in the soil.

In soils, however, in addition to the salts, we have to reckon with the presence of the absorbing complex as well as unweathered silicates. Water and CO_2 dissolve them very slowly, even more slowly than the $CaCO_3$. A certain proportion of the dissolved cations was originally in an absorbed form or as silicate constituents in the soil and has been dissolved in the water extract in the form of bicarbonates. Any reconstruction of the original salts of the soil from the composition of the water extract must be somewhat arbitrary—but not necessarily irrational. Let us see what can be deduced in this respect from the composition of the six soil profiles. For this purpose we need the further data given in Table XXXIX.

It will be seen that soils 1, 4 and 5 are abundantly provided with $CaCO_3$ in all their horizons, while the upper horizons of soils 2 and 3 are absolutely deficient in carbonates, and the whole profile of soil 6 is free of carbonates. In reaction, the Hungarian black steppe soil is slightly alkaline throughout its profile; the degraded steppe soil (No. 2) and the black meadow soil (No. 3) are slightly acid in their upper horizons, a fact indicated in particular by their high degree of hydrolytic acidity. In the other three soils we have not determined the reaction of the soil in such detail and can say only that the Spanish rendzina (No. 4) and red soil (No. 5) are neutral, and the soil on granite (No. 6) slightly acid.

If we apply the above argument to the six soils, we may assume that the Cl and SO_4 ions are in most cases present as sodium salts, while the dissolved K, Mg and Ca are usually present as absorbed cations or as carbonates. This general rule may change with soil type and soil horizon. In the case of the steppe soil, for instance, in the upper horizons the equivalents of sodium exceed the sum of the equivalents of Cl and SO_4 anions (Table XXXVIII.); while in the deepest horizon the reverse is the case, showing that in addition to sodium some potassium and magnesium are also combined with Cl and SO_4.

In soil No. 3, SO_4 is the predominant anion, a phenomenon which is closely connected with the genetics of the soil, which originates

TABLE XXXIX

No. and Depth of the Soil.	CaCO$_3$ %	MgCO$_3$ %	pH		Hydrolytic Acidity.
			In H$_2$O	In KCl	
1. 0-30	5·83	0·63	8·41	7·70	3·18
30-60	12·03	0·93	8·48	7·79	2·22
60-90	16·62	1·50	8·44	7·89	1·61
90-120	15·55	1·71	8·49	8·12	1·29
120-150	14·60	2·04	8·41	7·99	1·71
2. 0-30	——	——	7·02	6·07	15·00
30-60	——	——	7·02	5·90	13·38
60-90	——	——	7·47	6·28	7·10
90-120	4·41	0·12	8·65	7·82	1·42
120-150	10·63	0·51	9·05	8·30	0·40
3. 0-30	——	——	6·71	5·65	16·02
30-60	1·66	0·14	7·84	7·05	6·08
60-90	18·37	0·50	8·23	7·20	4·30
90-120	17·26	0·66	8·11	7·14	3·46
120-150	not determined.		8·20	7·16	3·70

Soil Horizon.	Total Carbonates as CaCO$_3$ %		In H$_2$O	In KCl	
4. I.	48·62		7·2	not de	termined.
II.	54·36		7·3	,,	,,
III.	54·22		7·1	,,	,,
5. I.	5·84		7·2	,,	,,
II.	47·94		7·2	,,	,,
III.	55·99		7·3	,,	,,
IV.	87·56		7·2	,,	,,
6. S.	—		6·9	,,	,,
I.	—		6·7-6·8	,,	,,
II.	—		6·9	,,	,,
III.	—		6·7	,,	,,

from a kind of moorland in its initial stage of development. In this case the soil contains not only Na, K and Mg sulphate, but some gypsum too.

In soil No. 4, we have to do with a typical Ca soil. as evidenced by the high proportion of exchangeable CaO (Table XXXVII.) throughout the profile. The sum of the equivalents of Cl and SO$_4$ ions is so small that it is insufficient to bind chemically all the sodium equivalents. Consequently we are justified in assuming that the rest of the sodium and all the water-soluble K, Mg and Ca are present in the form of carbonates or absorbed by the soil.

Finally, in soil No. 6, which is free from carbonates, sulphate is the dominant anion, and the HCO_3 has been added only by the water containing some carbonic acid. Consequently, in this case the bulk of the dissolved cations has been absorbed by the absorbing complex. It is interesting to note that, though the exchangeable Ca is far in excess of the Mg (Table XXXVII.), just the reverse is found in the water extract.

As we have seen, the chemical composition of *the water extract may be very instructive for the chemical characterisation of a soil.* But, as I have pointed out, the soil extracts prepared in laboratories never correspond to soil solutions existing under natural conditions. For if any soil contains 25 per cent. humidity the ratio of soil to water is 3:1, and may become still narrower in drier seasons. In the laboratory we cannot extract any comparable solution in which the proportions of the dissolved constituents bear any mathematical relation to those present in the natural soil. In more concentrated soil solutions *the proportion of the less soluble material declines and that of the easily soluble salts increases rapidly.*

There is much resemblance between the natural soil solution and drain water or water collected in lysimeters. But even in this case we get only the composition of the surplus water in the whole profile drained. A further disadvantage of drain water is that it gives only the final result of the course of percolation. The composition of the drained soil water *is useful for estimating the leaching processes in a soil profile, but unsuitable to explain the various interchanges which have taken place in each soil horizon.*

RAMANN and his collaborators have succeeded by high pressure (400-500 atm.) in obtaining some solutions of soils at natural humidity.* Unfortunately they determined only the chief plant foods, so that we have no idea of the full chemical composition of these natural soil extracts.

6. The Soil as a Source of Plant Foods.†

In the preceding discussions I have deliberately refrained from treating in detail the soil as a storehouse of plant foods. It is, however, the natural function of soil to serve both as physical support and as the source of food for vegetation. It would be a great mistake to exclude this function from a characterisation of soils. The soil type is sometimes directly related to the plant-food reserve of the soil.

* See RAMANN, E., MARZ, S., and BAUER, H.: Intern. Mitt. Bodenk., Vol. VI. (1916), p. 1.
† In the original Hungarian edition this chapter formed part of the section dealing with the biological characterisation of the soil. I have now combined it with the chemical characterisation of the soil, for most laboratory methods used to determine the readily accessible plant foods present in soils are chemical methods.

The tschernosems, for instance, are naturally rich in plant foods, and STEBUTT was right in stating that the steppe vegetation enriches the soil. We may add that the steppe vegetation cannot thrive on a poor soil. The reverse is true of soils formed under acid leaching conditions—*e.g.*, podsolisation or peat formation. In these cases the soil is almost permanently undergoing an acid leaching process, resulting in a considerable loss of readily soluble plant foods. Moreover, in this case the formation of the absorbing complex is very slow, and when there is any complex at all, it is highly unsaturated and consequently unfavourable for plant-food adsorption. The whole dynamics of these soils are destructive to the plant-food reserve. In fact, these examples show that the whole dynamics of the soil are directly connected with the plant-food reserve and its practical evaluation.

In this respect we differentiate between the total or ultimate and the readily-soluble or available plant-food reserve. The former has hardly any practical importance except in extreme cases, when the soil is very rich or extremely poor in some plant foods. On the other hand, it is not possible to determine in advance the exact amount of plant food which may be available for the next crop. For pot or field or Neubauer experiments give only figures showing the amount of plant foods taken up by the plant in the particular conditions of the experiment, and it is not easy to transfer these results to the conditions of ordinary crop production. In the case of chemical methods we can only estimate quantitatively the reserve from which the plant roots can take up their nutrients; but this does not mean that the reserve will be taken up quantitatively by a crop. Nevertheless, the amounts of plant foods which are readily dissolved by plant roots (NEUBAUER'S method) or by some weak acid or alkali or by certain micro-organisms are characteristic for a soil. We cannot yet say which of these laboratory methods is the best, but we can definitely say that between the water-soluble and the slowly soluble parts of plant foods there is an intermediate moderately soluble part representing a mobile equilibrium between the two extremes, which equilibrium, even if momentarily disturbed, may be restored at the cost of the slowly soluble part. If the proportion of this intermediate part is considerable, we have a relatively rich soil; and if its amount is small, the soil may be poor for crop production. The great difficulty lies in estimating those limit values which indicate richness or poverty of a soil in the several plant foods.

When fixing the limit values of certain plant foods it is a great mistake to give rigid figures. For so many various factors may influence plant nutrition and development, and so different may be the special needs of certain crops, that small variations of the limit values are of no practical importance. It is very probable, also, that the limit values may vary according to the soil type which best represents the general character of the dynamic changes taking place in a soil.

I have found, for instance, in the case of readily soluble phosphoric
acid that the limit values vary with the basicity of the soil.*   In my
opinion much uncertainty or controversy could be eliminated in this
kind of work if we restricted the limit values to the general dynamic
character of the soil.

* See SIGMOND, A. A. J. DE: Journ. Amer. Chem. Soc., Vol. XXIX. (1907),
No. 6, and Verh. d. II. Komm. Int. Bodenk. Ges.   Budapest (1929);
TEIL, A.: " Zur Frage der Laboratoriumsmethoden z. Best. des Düngerbedürf-
nisses des Bodens."

PART III

SOIL SYSTEMATICS

CHAPTER XII

INTRODUCTION

HAVING familiarised ourselves with the special characteristics of soils, let us now apply our knowledge to actual soils, and thereby endeavour to do what has already been done by other natural sciences possessing fully developed systems—viz., to give a systematic classification of soils. The attempts made hitherto to classify soils are really nothing more than the precursors of a definitive soil system.

By way of introduction I shall explain in brief the fundamental principles underlying the best-known systems of soil classification. LINNÉ, the great botanist, classified soils on the basis of natural vegetation or of physical or chemical constituents. The later system of THAER served primarily a practical purpose—viz., the valuation of fertile soils. This was the beginning of the practical classification of soils, which—while certainly taking into account the various peculiarities of the soil—either expressly or tacitly based its differentiations upon the degree of fertility. FALLOU accepted a geological classification as a scientific basis. All these systems, however, suffer from the common defect that they restrict themselves to very narrow limits and cannot be applied generally. Nor is the mechanical composition of the soil the property upon which it would be possible to build up a soil system of universal application. This fact was realised by the American soil scientists who did not content themselves with merely showing the parent rock and the mechanical composition, but established certain " series " or types called after the places where they were first located. Thus these scientists voluntarily acknowledged that neither the parent rock nor the mechanical composition is sufficient in itself to characterise the various soils, and that there are certain types which are to be found in several different places. In this way they determined a large number of " series," though without having arrived at any system of universal application. They did indeed endeavour to group " series " resembling one another; but they did not know—nor did they inquire into—the inner relationships, and consequently failed to arrive at any natural soil system.

The classification of soils on a geological basis was developed by

RICHTHOFEN introducing various climatic types or zones of weathering, thus acknowledging that climate exercises a decisive influence upon the nature of the weathering of rocks. I do not propose to deal exhaustively with this system; the only reason why I mention it is that it apparently resembles that of DOCUCHAIEV. The latter differs, however, materially from RICHTHOFEN's system, for DOCUCHAIEV does not look upon soils as merely weathered rocks but as the functions of all the soil-forming factors. DOCUCHAIEV distinguished the following distinct soil-forming factors:

1. The nature of the parent rock.
2. The climate of the place where the soil is found.
3. The character and amount of the vegetation.
4. The stage of development of the locality.
5. The local orographic conditions.

We see, therefore, that DOCUCHAIEV took into account the majority of the soil-forming factors known today, and we cannot regard his conception as one-sided—as tending, for instance, to group soils exclusively on the basis of climate and vegetation. What he was anxious to discover was the nature of the circumstances of formation of which the several soil types are the inevitable results.

His system of classification of soils is therefore genetic, whereas RICHTHOFEN's is based solely upon the geological origin—though he realised that the weathering of rocks differs in character according to the nature of the climate to the effect of which it is exposed.

The zonal system of SIBIRTZEV—somewhat modified and enlarged—remained long in vogue in Russia, where the conditions of soil formation really favour the zonal development of soil types. But the soils found zonally in Russia are found elsewhere in smaller extent either intrazonally or azonally, for which reason GLINKA formulated another system, from which he eliminated as far as possible the geographical distribution of soils. GLINKA's soil system is based on types of soil-formation independently of the geographical position of the places where the soils are found. Thus, the system of SIBIRTZEV—the division into zonal, intrazonal and azonal types—loses in importance, and the types of soil formation are grouped on the basis of the conditions of humidity. GLINKA's leading idea is that *the principal regulator of the dynamic phenomena contributing to soil formation is the degree of humidity prevailing in the soil.* There are indeed cases in which the original rock offers a prolonged resistance to this reaction, but unless *inner dynamic* factors of this kind impede the action of *outer dynamic* factors, the degree and manner of that action will adjust itself to the conditions of humidity of the soil. GLINKA divided the types of soil-formation into two principal groups—viz., *ectodynamomorphic* and *endodynamomorphic.* The latter soils he classifies as only transitional in character, as they join the group of normal ectodynamomorphic soils the moment the resistance of the parent

rock ceases. GLINKA's definitions of the conditions of humidity, however, were not quantitative, and were anything but definite (see his book on the subject).

Later, GLINKA abandoned this attitude, and instead merely differentiated the principal types which in his previous classification had characterised the various dynamic systems. He entirely omitted the endodynamomorphic soils, the result being that the so-called *rendzinas*—black earths formed from limestone—were left out of his system. The system has the undoubted advantage of being simple and comprehensive. It is certainly an advance that the alkaline soils and the fen soils have been included among the main types, being placed on a level with laterites, podsols and tschernosems, whereas in the systems of classification of DOCUCHAIEV and SIBIRTZEV they are treated separately from the normal types.

Thus in his later system GLINKA abandoned the previous methods of the Russian school, which had selected *one* of the soil-forming factors as the basis of its system, and he *adopted as his units easily distinguishable soil types*.

GLINKA's classification—at least in its outward manifestations—denotes the abandonment of soil-type zones. But his five main types and the sub-types included therein are not the only types of soil known to exist in the world. In consequence, scholars have begun to determine a whole series of types and varieties and to attempt to reduce them to a system. One of the most recent systems of the kind is that invented by VILENSKY. In this system the distribution of soils is based upon *analogous series of soil formations*. The fundamental idea underlying the system is that in the formation of soil we can distinguish several peculiar and genetically independent groups, which VILENSKY calls " divisions." Within each of these " divisions " he distinguishes six grades of soil formation—beginning with the transformation of the crude rock and passing through various grades to the completely developed main type of each " division." This is not, however, the end of the development, but merely the beginning of a process of destruction which ultimately results in simple decomposition products.*

GEDROIZ's system of soil classification is based upon the character of the absorbing complex of the soil and upon the quantity and quality of the absorbed cations; but, as GEDROIZ himself has repeatedly explained,† the development and rate of saturation of the absorbing complex is *the result of the genetic factors*. His system of classification, therefore, is also genetic, differing from the other systems in that the classification is based, *not upon assumed soil-forming factors*, but on the composition of the absorbing complex *resulting from the effect of soil-forming factors*. His system naturally does not include all soils,

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* See VILENSKY, D.: Proceed. Int. Soc. Soil Sci., Vol. I. (1925), p. 224.

† See GEDROIZ, K. K.: " Der absorbierende Bodenkomplex " (Th. Steinkopff, Dresden and Leipzig, 1921).

for however characteristic the humus-zeolite complex may be of certain soils, there are nevertheless other soils from which that complex is altogether absent or in which the part it plays is relatively insignificant.

The formation or destruction of the humus-zeolite complex is the basis also of the dynamic system of STEBUTT.* Here, too, the pivot of the classification is GEDROIZ's absorption theory; but, while GEDROIZ developed the zeolitic theory more broadly, extending it to all known soil types, STEBUTT finds means to include in his system also those soils in which there is no zeolite complex. As compared with GEDROIZ's system, STEBUTT's possesses the advantage of not fixing such rigid criteria for the saturation of the absorbing complex. In any case, one of the general fundamental principles of STEBUTT's genetic classification is that the phenomena found in nature cannot be regarded as absolute, but at all times only as relative.†

In my opinion STEBUTT's dynamic classification of soils suffers from two defects: (1) the basis upon which the system rests presupposes many facts still to be proved; (2) although it embraces all known soils, it is nevertheless undeveloped as a whole.

Of recent years an increasing number of American soil scientists have accepted the Russian system of classification; while practically all the American pedologists are endeavouring to eliminate the general defects of the Russian systems referred to above. In MARBUT's soil system, for instance, we find the various Russian soil types; but the system is also developed in both directions (upwards and downwards) to contain seven categories, the lowest of which (I.) comprises the soil units, the highest (VII.) comprising the main groups of the seventh category.‡ The essential difference between this system and that of the Russian school is that it bases the classification not on factors outside the soils, but on characteristics of the soils themselves.

MARBUT's soil system is complete in its way, for it starts from the most general category and passes through several stages to individual local soils. It also differs from the older Russian system in that the classification is not based upon one or more soil-forming factors, but on the known soil types themselves. When the Hungarian edition of my book appeared we had only the rough draft of MARBUT's soil system. Now I have been able to procure his Atlas of American Agriculture, Part III., in which the whole system is worked out. The space available is too limited to describe and discuss this work in detail, but in describing my own system I shall refer to it where necessary.

At the same time other American scholars published draft soil

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* See STEBUTT, A.: "Lehrbuch der allg. Bodenlehre" (Gebr. Borntraeger, Berlin, 1931).

† See the passage referring to this matter on p. 296 of STEBUTT's book, and also the footnote on p. 367.

‡ See COFFEY, G. N.: Dept. of Agric. Bureau of Soils Bull., No. 85 (1913).

classifications apparently intended to reconcile the American system with that of the Russian school, though by making the definite characteristics of the soils serve as the basis of classification and not confining classification to a characterisation of the main types. A draft classification of this kind is SHAW's, which attempted to systematise the soils of California.* The American scientists in general accepted the genetic principle of the Russians, but very properly objected that *a scientific system cannot be based on outside factors*, the only rational basis being the characteristics of the soil itself. This point was stressed most emphatically by RICE, of the American Ministry of Agriculture.† RICE did not wish to disparage in any way the great significance attaching to a study of the genetic factors; all he desired to do was to point out that *only the peculiar characteristics attaching to the soil itself can serve as basis for classification*, that being the method employed in botany, zoology and mineralogy.

It should be noted (as may be seen from what has been said above) that the Russians (*e.g.* GEDROIZ) have also recently reverted to a system of classification based upon the intrinsic properties of the soil, while most soil scientists find the Russian system hitherto in force to be unsatisfactory. A certain importance nevertheless attaches to all the various systems as having led us to regard the soil as the result of the action of the various soil-forming factors.

Not having found among the systems of soil classification so far known any which, *while sufficiently comprehensive and based upon the characteristics of the soil, is nevertheless genetic and dynamic in character*, I have established a new system based on the results of leaching experiments.‡ I shall describe this system in the following chapters, at the same time characterising the best-known soil types.

CHAPTER XIII

THE GENERAL SOIL SYSTEM

THIS system is based on soil characteristics which enable us to include all known soils in a uniform soil system, characteristics which fairly reflect the present state not only of soil conditions, but also of the dynamic forces acting in the soil. In this respect it rests on a genetic basis. For if the present dynamics of the soil are similar to those which operated during its development, we have to deal with a well-defined soil type. If, however, the present dynamics of the soil

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* See SHAW, C. F.: Proc. Pap. I. Int. Congr. Soil Sci., Vol. V. (1928), p. 65.
† See RICE, T. D.: Proc. Pap. I. Int. Congr. Soil Sci., Vol. V. (1928), p. 108.
‡ See SIGMOND, E.: Math. Term. Tud. Ért. (Math. and Natural Science Journal), Vol. XLIV. (1927), p. 510; Proc. Pap. I. Int. Congr. Soil Sci., Vol. I. (1928), p. 60.

tend in a different direction from before, we have to deal with soil metamorphosis and its various forms and stages, and it is the work of the soil expert to ascertain the real characteristics of the present dynamic conditions of the soil. For that reason this general soil system, though genetic in some respects, may also be called a dynamic soil system.

The so-called "zonal" and "regional" soils are naturally all included in this system, and also the so-called "intrazonal" and "azonal" soils which are in some respects independent of the external soil-forming factors. Thus this system deals not with zonal or regional soils, but with main groups, sub-groups, soil orders, main types, sub-types, local varieties, physical and physiologic classes. These eight categories form the eight stages of the whole system, not excluding, however, the further development of the system for purposes of more specific differentiation. The first stage of the system is the most general and the eighth the most special of the categories—i.e., the reverse of MARBUT's system. The unit of each category is based on the same property—viz., the dynamic conditions of the soils. The most universal dynamic conditions determine the units of th
and the most specific ones those of the last stage. I   il scientists
our general soil system resembles the known system practically
zoology and other branches of natural philosophy. The general
tion of the units of each soil category is done in all   MARBUT's soil
accessible soil characteristics and not by externa   types; but the
climate, natural vegetation or topography. Thou nd downwards)
of our present knowledge does not allow us to buil   comprises the
of the different stages of the system, the fram   groups of the seventh
enough to embrace almost all future branches   is system and that of
and worked out later on. Moreover, each s   ication not on factors
new units, and as the last stage is the mc   ils themselves.
opportunity to enlarge the range of stages   for it starts from the
greater specificity. In this way the whole   l stages to individual
elastic—a property which is especially necessar   n system in that the
science such as modern pedology.   forming factors, but

Stage I. Main Groups.—All soils on the ea Hu
classified in three main groups according to the origin of their parent material:

> 1. Organic soils.
> 2. Organic and mineral soils.
> 3. Purely mineral soils.

It may be noted that the group-characterising properties here and in the succeeding discussions are not strictly exclusive. For instance, in the organic soils, namely the various turf and peat soils, we shall always find some mineral element also, but the latter has *no importance in the present dynamics of the soil.* The most independent of the underlying parent rock is the high-moor land with its-
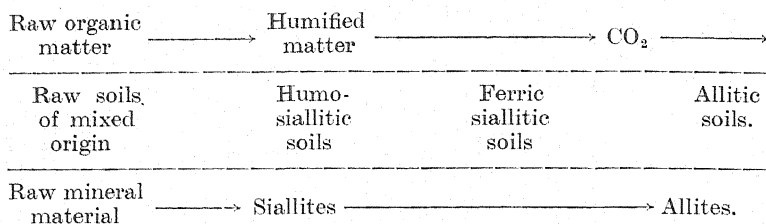
poor specific vegetation, living on almost pure rain water. The demand on nutritive materials being greater in the case of low-moor vegetation, the mineral matter has somewhat more influence on the formation and development of low-moors, but if the moor land is thick enough, the characteristics of the soils are also almost independent of the underlying parent materials. Consequently they also belong to the main group of organic soils. If, however, the chief characteristics of the soil depend on the inorganic constituents originating from the parent minerals, and the organic matter is merely a subordinate element, the soil belongs to the second main group—i.e., it is of organic and mineral, or briefly, of mixed origin. To this main group belong most cultivated lands. Finally, the third main group includes all the desert soils, which are entirely deficient in organic matter, due to the extreme climatic conditions—for instance, extreme cold or dryness which inhibits any vegetation.

Stage II. Sub-groups.—These are based on the various dynamic conditions of the original soil-forming materials. Both the organic and inorganic soil materials tend to decompose. The decomposition passes through various stages. In the decomposition of soil organic matter we may distinguish four phases: (1) the original, dead, raw material; (2) the insoluble product of humification; (3) the soluble or peptised humus materials; (4) the gaseous end-products (CO_2, CH_4, H_2, NH_3, etc.) of the decomposition. As, however, in the case of organic soils the third and fourth phases in themselves are not soil-forming materials, the first main group may be divided into two sub-groups: (1) raw organic soils, and (2) humified organic soils.

In the case of pure mineral soils we can distinguish three phases: (1) raw mineral soils, (2) pure weathered mineral soils, and (3) purely mineral soils infiltrated by some end-products (salts) of the weathering.

The greatest variation is found in the soils of mixed origin. For in this case the various stages of the soil organic matter decomposition coincide with the various stages of the mineral weathering. To characterise roughly the course of decomposition of the mineral matter I have found it best to distinguish three stages: (1) raw mineral matter, (2) siallites, (3) allites. The fundamental idea of this differentiation is that the first stage is the raw material itself; the second a well-defined intermediate stage, viz. the prevalence of siallitic material; and the third stage is the end-product of the weathering and leaching of the silicates—the so-called allites. By analogy with this idea we may distinguish the following three stages of decomposition in soil organic matter: (1) raw organic matter; (2) humified organic matter; (3) the end-product of the decomposition of soil organic matter, viz. carbonic acid, in which stage the decomposition of organic matter in the soil is so complete that practically no humus remains in the soil, all the carbon being transformed into CO_2. Theoretically the combinations of the different stages of the two original soil materials can be very numerous. In nature, however, the de-

composition of both materials runs almost parallel, as may be seen from the following diagram:

Raw organic matter	→	Humified matter	→	CO_2 →
Raw soils of mixed origin		Humosiallitic soils	Ferric siallitic soils	Allitic soils.
Raw mineral material	→	Siallites		→ Allites.

In accordance with these combined phases the second main group may be divided into four sub-groups:

1. Raw soils of mixed origin including all soils in which the decomposition of the organic and mineral materials was for some reason inhibited.

2. Humus-siallitic soils, embracing most of the cultivated and forest land in temperate climates and representing mineral soils of siallitic character with a true humiferous horizon.

3. *Ferric siallitic soils* characterised especially by the colouring effect of ferric compounds and a predominance of siallites.

4. *Allitic soils* characterised especially by a predominance of allites (Al_2O_3, Fe_2O_3, combined H_2O) and extreme leaching of bases.

The soils of sub-groups 3 and 4 are found mostly in the sub-tropics and tropics.

To get a clear synopsis of the differentiation and chief characteristics of the main and sub-groups we may summarise our definitions as in Table XL.

Stage III. Soil Orders.—While in the second stage we have classified soils according to their general dynamic conditions, in the third stage the classification is based upon the various specific features of the soil dynamics. The dynamic character of the soil may be defined by those physical, chemical and biological changes which have had, and still have, a decisive influence on the formation of the soil profile. For instance, the hydrogen of the absorbing complex plays a dominant rôle in soil formation in cases of acid soil leaching. If we consider those well-known soil types in which soil formation is due primarily to acid soil leaching we find various soil types belonging to this category. It has therefore proved useful to group the well-known soil types with a similar dynamic character in the same higher stage of the soil system. Originally I called this category soil " species." But as this term has already a well-defined and narrower sense in botany and zoology, I have replaced it by the term soil " order." This category represents a kind of super-type, comprising some kindred soil types in a higher group based on their common dynamic character. This stage of my soil system is intermediate between the sub-groups and the main

TABLE XL

Main Groups.	Sub-groups.
I. *Organic soils*, the organic matter ($C \times 1\cdot72$) exceeding 25-30 per cent. and the depth of the organic layer 25-30 cm.	1. *Raw organic soils*, characterised by visible botanical structure of the surface layer. 2. *Humified organic soils*, the botanical structure of the surface layer being invisible.
II. *Soils of mixed origin*, the organic matter not exceeding 25-30 per cent., and the depth of the surface layer, if organic itself, not exceeding 25-30 cm.	3. *Raw soils of mixed origin*, in which decomposition of the raw materials is almost absent or the soil has no characteristic profile. 4. *Humo-siallitic soils* characterised by various degrees of humification, and in the HCl-extract $SiO_2:Al_2O_3 > 2:1$. 5. *Ferric-siallitic soils*, the typical colour of the soils being due to Fe_2O_3-compounds, and $SiO_2:Al_2O_3 > 2:1$ in the HCl extract. 6. *Allitic soils*, characterised by extreme soil leaching and $SiO_2:Al_2O_3 < 2:1$ in the HCl extract.
III. *Purely mineral soils*, containing no living or dead organic matter.	7. *Raw, purely mineral soils.* 8. *Purely mineral soils with initial weathering.* 9. *Purely mineral soils encrusted with some end-products (salts) of mineral weathering.*

types. The more general dynamic standpoints are developed by further differentiation towards greater specificity, while the well-known soil types are grouped as main types in higher units according to their chief dynamic characteristics.

We begin with the soil orders of sub-group 4—viz., the humo-siallitic soils—because the bulk of the best-known soils belong to that sub-group. For the characterisation of these soils we have already abundant evidence showing that in the humo-siallitic soils the humo-zeolite complex plays the most prominent rôle. GEDROIZ and STEBUTT have built up their soil classification almost exclusively on the saturation conditions of this absorbing complex. According to my own experience the soils of the humo-siallitic sub-group may be divided into three well-defined soil orders—viz., calcium, hydrogen and sodium soils.* In the case of the calcium soils (Ca soils) the absorbed Ca cations and in the case of hydrogen soils (H soils) the absorbed hydrogen ions dominate the soil dynamics, while in sodium soils (Na soils) the absorbed sodium cation is sufficient to exercise a special effect on the

* See SIGMOND, A. A. J. DE: " The Chemical Characteristics of Soil Leachings," Proc. First Int. Congr. Soil Sci. Wash., 1927, Vol. I., p. 60.

soils, most of which are known as alkali soils.   By this I do not mean
that we may not find other humo-siallitic soils in which, for instance,
magnesium or potassium supplies some characteristic features, and in
time we may be forced to include magnesium or potassium soils also
among the soil orders of the humo-siallitic sub-group; but before
knowing better the characteristics attributed to these soils by some
authors, we cannot accept them as soil orders.

The best-known main type of the Ca soil order is the tschernosem.
In tschernosem soils there are enough active Ca cations to determine
the general dynamic character.   The absorbing complex of the soil
is nearly saturated, and the proportion of the exchangeable Ca cations
is about 75-80 per cent. of the total equivalents of the exchangeable
cations—viz., of the S-value of HISSINK.   We have found the same
in the case of rendzinas, another main type of the Ca soil order.   As
will be seen later, we can at present include in this order eight different
main types with the same dynamic character.

The best-known main type of the H soil order is the common forest
soil of temperate boreal climate.   The general character of the dynamics
of these soils consists in the active H ions exercising a dominant
influence on the existing soil phenomena, giving to the soil solution
a more or less acid character.   In these soils the absorbing complex
is more or less unsaturated and among the exchangeable cations the
proportion of sodium is very insignificant.   In the same soil order we
may include all podsolised or degraded soil types, their absorbing
complexes being also unsaturated, with the exception of the degraded
alkali soils, which belong to the sodium soil order.

The sodium soil order embraces all the alkali or salty soils of the
humo-siallitic sub-group.   The salty soils of the purely mineral main
group are excluded on account of the absence of any humo-zeolite
complex.   In the case of true Na soils the sodium cations exercise
a specific influence on the whole dynamics of the soils belonging to
this order.   The sodium cations in these soils are found either in the
form of water-soluble sodium salts or in exchangeable form, or in both
forms simultaneously.   Apart from the predominance of sodium
cations the absorbing complex may be saturated or unsaturated, the
absorbed or exchangeable sodium exercising a far greater dispersing
effect on the soil colloids than the absorbed hydrogen.

In Table XLI. I have summarised the chief characteristics of the
three soil orders discussed above.

In the sub-group of ferric-siallitic soils, which are very frequently
poor in humus, the dynamic conditions are not yet known as perfectly
as in the soils of the humo-siallitic sub-group.   The best-known soil
order in this sub-group is the order of red earths, the literature of
which is very rich.   Nevertheless, we find many unsettled questions
and contradictory statements, which make it difficult to give a clear
characterisation of the soil dynamics of this soil order.   The same
might be said with even more emphasis about the brown earths and

TABLE XLI

	H-Soil Order.	Ca-Soil Order.	Na-Soil Order.
pH	Below 6·5-7·0	6·5-8·3	6·5-10·0 or more.
Absorbing complex:	Unsaturated; exchangeable Na insignificant.	Saturated chiefly by Ca, partly by Mg.	Exchangeable Na more than 12-15 equivalent per cent. of S-value, or the Na-salt content is higher than 0·15 per cent.
Colloid dispersion:	Fairly stable.	Unstable (coagulated).	Stable.
General character of profiles:	ABC	AC	ABC

yellow earths. All these three soil orders, however, are alike in being typical chromatic soils depending mainly on the differences of colour of the ferric iron in them, and upon the ratio of $SiO_2 : Al_2O_3$ or the so-called Ki-value not being below 2. This means that though some allites may be present siallites predominate. The quartz content is not included in the Ki-value. Hence the $SiO_2 : Al_2O_3$ ratio of the HCl extract determined by the VAN BEMMELEN-HISSINK method, now internationally accepted, is at present the simplest way to get reliable figures. Some workers determine the total chemical composition of the colloidal part of the soils and use the ratio of $SiO_2 : Al_2O_3$, calculated from the results of the fusion analysis of the colloidal fractions. If, however, we have no reliable evidence of the absence of fine quartz, felspars or other silicate minerals the various ratios may be misleading. It is sometimes difficult to distinguish between the red and yellow earths respectively. MARBUT places them in a common section;* he remarks, however, that "the red or reddish soils occupy regions where drainage is good and where the water table lies many feet below the surface. Yellow soils occur predominantly on smooth relief where ground water stands at a depth of a few feet, usually immediately below the solum or has stood at that position until a very recent geological date." MARBUT's intention was to give some explanation of the genetic relations of the red and yellow soils in the United States of America.

The allitic soils or allites are commonly known as laterites. In their outward appearance they resemble red soils, but in their chemical composition they differ fundamentally from the latter in that the

* See MARBUT, C.: "Atlas of American Agriculture," Part III., p. 40.

SiO_2 and the bases in the allites are far more leached out than in the case of red soils. The Ki-value is usually far below 2 and the proportion of bases (Ca, Mg, K and Na) is very low. HARRASSOWITZ distinguishes two kinds of allitic soils or laterites according to whether the layer of decomposition is siallitic or allitic. In the same way I distinguish in the sub-group of allites pure allites and siallitic allites respectively. In addition to that we have some evidence of the occurrence of allites of grey colour due to the absence of iron. This group of allites forms the third order of the sub-group.

It was not easy to differentiate the sub-group of raw soils of mixed origin. In his book STEBUTT designates the raw soils as adynamic soils and distinguishes three kinds of *adynamic* soils—*endo*-, *ecto*- and *pseudoadynamic* soils. In the case of *endoadynamic soils* the chemical composition of the soil material in itself precludes any essential changes, while in the case of *ectoadynamic soils* the parent material is capable of chemical transformation, but external conditions prevent any changes. Finally, in the case of *pseudoadynamic soils* the material of the soil is not adynamic in itself, but there has not been any opportunity for the development of a typical soil profile. They are, therefore, not real raw soils, but only pseudoadynamic.

Summarising the soil orders of the main group of soils of mixed origin, we get the following scheme:

MAIN GROUP II.: SOILS OF MIXED ORIGIN.

Sub-groups.	*Soil Orders.*
Raw soils of mixed origin	Endoadynamic soils. Ectoadynamic soils. Pseudoadynamic soils.
Humo-siallites	Hydrogen soils. Calcium soils. Sodium soils.
Ferric-siallites	Brown earth. Red earth. Yellow earth.
Allites	Pure allites. Siallitic allites. Bauxitic allites.

In main group I., I have distinguished two sub-groups—raw organic soils or turf soils and humified organic soils or peat soils. Both are products of moor land and both are commonly spoken of as peat soils. It is, however, necessary to make the above distinction and to restrict the term " peat soil " to the narrower sense. Ordinarily peat soils are classified in two main groups of high-moor peats and low-moor peats according to the nature of the hydrophyte vegetation which has formed the peats. It is, however, essential from a pedological point of view to differentiate between a raw organic soil, which is still in a condition not yet far removed from unaltered moor land and

a humified organic soil, in which the original botanical structure is already indistinguishable owing to the advanced humification.

Usually turf soils and peat soils are also grouped according to their botanical composition—viz., *Sphagnum*, *Eriophorum*, *Scirpus*, *Carex*, *Hypnum*, heath, peats, etc. When we consider, however, that the botanical nature of the moor vegetation depends primarily on the nutrient conditions of all these hydrophytes, we may distinguish three grades: (1) hydrophytes living in water very poor in bases (*Sphagneæ* and other high-moor vegetation), (2) hydrophytes preferring water rich in bases but not rich in sodium salts, (3) hydrophytes living in salt water. On this point the analytical data of FLEISCHER are very instructive.[*]

			Ash %.	P_2O_5 %.	K_2O %	CaO %.	N %.
Sphagnum turf	..	..	2·0	0·05	0·03	0·25	0·8
Heath turf ..	..	..	3·0	0·10	0·05	0·35	1·2
Low-moor turf	..	..	10·0	0·25	0·10	4·0	2·5

These figures are average values of numerous investigations, showing that the typical high-moor turf (*Sphagnum*) is very poor in comparison to low-moor turf in all plant nutrients and in ash content. GULLY has studied[†] the different varieties of *Sphagneæ*, and found that those living on high-moor lands are very poor, while those which thrive well on low-moor lands are relatively rich in nutrients and bases. This shows again that it is more accurate to speak of turfs poor and rich in bases respectively, than to use the botanical species as the group determinant.

Accordingly, I have distinguished three orders in the sub-group of raw organic soils: (1) *turfs poor in bases*, (2) *turfs rich in bases but not salty*, (3) *salty turfs*.

In the case of humified organic soils we have analogous groups, the difference between turfs and peats lying chiefly in the more advanced humification of the latter. It may be noted here that in any case the quality of the surface layer determines the designation of the organic soil orders, for it very often happens that in a profile of high-moor land the deeper layers are residues of low-moor land. We might also find under a humified organic layer (peat) a raw organic layer (turf). It is therefore necessary to designate all organic soils according to the quality of the surface layer which determines the present dynamics of the soil.

As those peats which are rich in bases are approximately saturated or neutral while those which are poor in bases are unsaturated or acid peats, the analogous soil order of peats may be designated as follows: (1) unsaturated (acid), (2) saturated (neutral or slightly alkaline), (3) salty peats.[‡]

[*] See BERSCH, W.: Ztschr. Moorkult. Torfw., Vol. V. (1907), p. 65.

[†] See GULLY, E.: Mitt. d. kgl. bayer. Moorkulturanstalt (1913), No. 5.

[‡] The Sub-groups 1 and 2 correspond with the basic idea of DACHNOWSKI-STOKES's " oligotrophic " and " eutropic " main groups, which were described after my Hungarian book was issued. See DACHNOWSKI-STOKES: " Trans. Third Int. Congr. Soil Sci.," Oxford, 1935, Vol. I., p. 416.

It was not easy to classify the sub-groups of the purely mineral soils, as our knowledge of the desert soils is not sufficient for classification. The raw purely mineral soils are chemically undecomposed, only mechanically disintegrated. In this case, however, it is incorrect to use the terms common in mechanical soil analysis. These soils occur in three different climatic regions—viz., in arctic regions, in mountain regions of perpetual snow, and in tropical deserts. In the latter case the high insolation in the day-time and the cool nights act as strong dynamical disintegrating factors. In the arctic and snow regions ice has about the same splitting effect. In all these cases the mixed rock débris are mostly irregular angular pieces of varying size from large boulders to very fine dust. These are soils of mixed rock débris. If, however, some dynamic factors (wind or water) distribute the mixed débris into variously sized fractions, we may get soils of mineral grits or of fine mineral dust. It seems to me that at present it is sufficient to distinguish only the above three grades of raw, purely mineral soils. When we know more we may easily add some other grades. For a long time we did not believe that any chemical decomposition was effected in desert soils. Recently, however, we have obtained evidence of an initial chemical weathering in some cases. There are desert soils in which a faint mobilisation of calcium, or else of silica, may be observed. These two soil orders represent subdivisions of the sub-group of purely mineral soils with initial decomposition.

Finally, I have included in my system the purely mineral soil with salt incrustation. Some writers regard them as simple geological formations and not as soils. This question is open to dispute. But when we consider desert soils in the field of soil science, we cannot omit the salty representative of this group, which cannot be regarded as an alkali soil in the sense given above since it contains neither humus nor siallites. In this sub-group it may be sufficient to distinguish two orders—viz., soils with easily soluble and soils with slowly soluble salt crusts. Summarising the soil orders of the whole third main group, we get the following scheme:

MAIN GROUP III.: PURELY MINERAL SOILS.

Sub-groups.	Soil Orders.
Raw, purely mineral soils	Soils of mixed mineral débris.
	,, of mineral grits.
	,, of mineral dust.
Purely mineral soils with initial decomposition.	,, in which the calcium is partly
	,, in which the silica mobilised.
Purely mineral soils with some end-product of soil weathering.	,, with easily soluble salt crust.
	,, with slowly soluble

If we consider now the geographical occurrence of the above soil orders, we very often find that some of them occupy large areas—typical soil zones. As a rule the H soils are spread over humid climates,

the Ca soils in arid or semi-arid climates; the red earths in humid tropics or sub-tropics, the laterites in humid tropics with intermittent dry periods; the sphagnum turfs are of frequent occurrence in cold, humid climates; the purely mineral soils, including all the seven soil orders characterised above, practically dominate the dry desert of the tropics.

The correspondence with the climatic zones does not mean, however, that the soil orders include only zonal soils. For—as we shall see later—we find as a main type of the Ca soils the rendzinas, which are not zonal but azonal soils, their occurrence depending not on climate but primarily on the quality of the parent rock.

As regards the order of sodium soils—especially those which we generally call alkali soils in the broad sense—they may be regarded as zonal soils in so far as their formation depends primarily on the aridity of the climate. But the alkali soils form hardly continuous soil zones, occuring mostly scattered in various other soil zones of an arid climate. In this respect they are intrazonal soils.

One great advantage of my dynamic soil system is that the zonal, azonal and intrazonal soils are all included in it. The MARBUT soil system puts all the azonal soils in Category III.—Local Environment Group (Family Group)—developed by local rather than general environmental conditions. As we shall see later on, however, their dynamics may be as characteristic as those of the " great soil groups " of MARBUT (Category IV.). Moreover, as we have seen when discussing soil genetics, the parent materials, the orography and hydrography of the environment are also integral soil-forming factors, as much as climate or natural vegetation. Systematically it makes, therefore, no difference if in some cases climate and vegetation, in others the parent material or the orography and hydrography of the soil environment, dominate soil dynamics. Differentiation of local and general environment groups is more geographical than pedological and leads to an almost complete neglect of the local environment groups. A result of this is, for instance, that in MARBUT's " Atlas of American Agriculture," Part III., among the soils of the United States we find neither the typical alkali soils of the west and south, nor the widely spread peats and turfs of the north and east. In the work recently issued by JACOB S. JOFFE* the various types of sodium soils (solonchak, solonetz, solodi), redzinas, etc., are put in one section as intrazonal soils. Thus the rendzinas are included in the same group as the various littoral soil formations (marsh soils), the alluvial soils, and the alkali soils. Soils of very different dynamics are included here in one and the same group, and are widely separated from those naturally related to them.

Again, in Chapter XIV., JOFFE treats quite separately bog and marsh soils which roughly coincide with my Main Group I.—organic soils—though he treats them quite independently of other soil types and does not connect them systematically with any other group.

* See JOFFE, JACOB S.: " Pedology," New Brunswick, N.Y., 1936.

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In my dynamic soil system we find no isolated soil groups to be treated on a different basis from others. In all stages of my system the distinctions are based on the principal dynamic character, and are systematically graded in eight categories or grades.

To give a clear survey of the continuity of the three highest stages of my dynamic soil system I have constructed in Table XLII. a genetic tree of the main groups, sub-groups and soil orders.

TABLE XLII

Stage I. Main Groups.	Stage II. Sub-groups.	Stage III. Soil Orders.
1. Organic Soils.	1. Raw organic soils— i.e., turfy soils.	1. Turfs, poor in bases. 2. Turfs, rich in bases but not salty. 3. Salty turfs.
	2. Humified organic soils —i.e., peat soils.	4. Acid peat soils. 5. Neutral peat soils. 6. Salty peat soils.
2. Organic Mineral Soils.	3. Raw organic mineral soils.	7. Endoadynamic soils. 8. Ectoadynamic soils. 9. Pseudoadynamic soils.
	4. Humic siallites.	10. Hydrogen soils. 11. Calcium soils. 12. Sodium soils.
	5. Ferric siallites.	13. Brown earth. 14. Red earth. 15. Yellow earth.
	6. Allites.	16. Pure allites. 17. Siallitic allites. 18. Bauxitic allites.
3. Purely Mineral Soils.	7. Raw mineral soils.	19. Soils of mixed rock débris. 20. Soils of mineral grits. 21. Soils of fine mineral dust.
	8. Mineral soils with some decomposition.	22. The calcium of the mineral matter partly mobilised. 23. The silica of the mineral matter partly mobilised.
	9. Mineral soils with the end-products of decomposition.	24. Soils with easily soluble salt crust. 25. Soils with slowly soluble salt crust.

At the Third International Congress of Soil Science in Oxford, 1935, I submitted a method by which we can determine the position of each soil in this scheme.* I hope I shall shortly be able to publish this soil register in English; it is helpful not only to soil surveyors and soil experts, but also to soil collections and soil museums.

CHAPTER XIV

CHARACTERISATION AND FURTHER CLASSIFICATION OF SOIL TYPES (STAGES IV., V. AND VI. OF THE SOIL SYSTEM)

THE position in the soil system of the various soil types is analogous to that occupied by the various kinds of rock (granite, liparite, trachite, etc.) in petrography. For just as a comparison of the peculiarities of the various kinds of granite enables us to give a general characterisation of that rock on the basis of its minerals and their crystalline structure, so we have been enabled with the aid of characteristics common to similar soil formations to determine certain soil types which may be grouped in higher units—main types—differentiated by their outer and inner properties. Main types of this kind are, for instance, tshernosems, forest soils, laterites, alkali soils, peat soils, etc. These main types do not represent the simplest units of the soil system; but a similarity of chemical properties lends them common characteristics that enable us to form a definite conception of the ideal example of each soil type.

In the three stages of the soil system already discussed we employed only the most essential genetic and dynamic properties for their characterisation and delimitation. In the first stage the distinguishing criterion was a common chemical (dynamic) character of the original raw material; in the second stage soils were grouped according to variations of the parent material; and in the third stage by the resultant effects of the dynamic changes. However, all these theoretical criteria were so far removed from the soil itself that it would have been difficult to characterise the order by a profile description, not to mention that an individual soil order often comprises a whole series of soil types connected only by some common properties of a general and higher character. The *Ca soils*, for instance, include tshernosems, brown and light-brown steppe soils, rendzinas, sub-tropical and tropical black soils, etc. These are soil types rather different in appearance and composition; but they have in common that they are all approxi-

* See SIGMOND, A. A. J. DE: Trans. Third Intern. Congr. Soil Sci., Oxford, 1935, Vol. I., p. 334; and Magy. Tud. Akademia Mat. Term. Tud. Ert., Vol. LIV. (1936), p. 894.

mately neutral or saturated soils, and that in their absorbing complex
the chief rôle is played by the Ca cations, this circumstance determin-
ing all the changes ensuing in the soil—in other words, its whole
dynamic system. This is true, not only of the tshernosems, but of
all the other soil types mentioned above, which cannot be regarded
as so many sub-types or variants of the tshernosem main type. This
fact is most patent in the case of the rendzinas. It was thus necessary
to group the soil types first in higher stages—viz., soil orders, which
are something like super-types.

In the present chapter we shall characterise the soil types by
detailed descriptions of the *main types*, though the main types them-
selves require to be further subdivided into *sub-types* and *local types*
or *varieties*. For that reason it will be expedient to treat each of the
main types in combination with its sub-types and local varieties.
In the case of tshernosems, for instance, after describing the funda-
mental characteristics of the main type itself, we shall proceed to deal
with sub-types of the various regions or soil zones and with the
peculiarities of the various local occurrences. It is expedient to treat
all three stages together, if only because all three stages demand a
detailed description of the respective soil profiles.

Consequently, in the following pages we shall deal with the character-
istic main types of each soil order separately as Stage IV., and then
with the several sub-types of each main type as Stage V., and finally
with the local varieties as Stage VI. of my soil system. Each section
of the present chapter treats of all the types comprised in one of the
soil orders.

The characteristics of the main types will be grouped as follows:
(1) genetic, (2) dynamic, (3) chemical, (4) physical and morpho-
logical, (5) biological. This facilitates a systematic comparison of
the several main types. I should emphasise that we ought to use
positive characteristics—such as are observable in the type itself—
for the purpose of determining the genetic, dynamic and biological
properties of the soil, just as we should use actual analytical or experi-
mental data in determining the chemical and physical properties.

Soil Order 1: Turf Soils Poor in Bases
(Main Type: Sphagnum Turf Soils, Raw or Turfy High-Moor Soils).

Genetic Characteristics.—In turf soils the development of the genetic
characteristics is apparent to the eye, and the best method of ascer-
taining the origin of a turf soil is to make a botanical analysis of its
profile. Genuine sphagnum turf is not formed except in conditions
of excessive humidity in places where the stagnant water is poor in
plant foods. It is formed in particular where the precipitation water
—which in itself is poor in nutrients—accumulates and where the
subsoil in which the water collects is also poor in plant foods. The
shortage of nutrients may be either due to the climate being a cold

one or to the poverty of the parent rock.   But it may happen that in the beginning a low moor is formed which then exhausts the nutrients, thus forming the basis upon which a sphagnum turf soil can form. The former case is common in arctic or cold climates and high mountains, while the latter is found also in temperate climates. RAMANN points out that sphagnum turfs are characterised by a plant association of arctic origin, and it is useless to look for these soils in warmer regions or climates.   In this respect the sphagnum turf soils may be regarded as zonal or regional formations, confined as they are to humid and cold climates.   At the same time, they are local formations, for they do not develop except where excessive water (precipitation, ground water, stagnant or slowly running water) accumulates for some local reason.

The vegetation of high moors is composed of various species of *Sphagnum*.   These plants do not require much nutrition, only an abundance of moisture, which their peculiar structure enables them to suck up like sponges.   The *Sphagnum* cover is highest in the middle, flattening and spreading over the edges of the original moor.   This increase in area of the high moor continues until its source of moisture for some reason or other is exhausted.   In older moors we find something suggesting such periodical exhaustions—the so-called *humified horizon*, which is found as a layer in the sphagnum turf and denotes the temporary suspension of the growth of mosses and the first stage of decomposition.

Where, for some reason or other, a moor dries up, the mosses gradually perish, their place being taken by other plants, such as heath or heather (*Calluna, Erica*) or certain species of conifers, which have low nutrient requirements.

Dynamic Characteristics.—Since fresh turf soils are practically adynamic, the only question arising here is as to the degree of decomposition.   A living moorland itself is only relatively adynamic; for its upper, living horizon is the scene of constant biological changes. The adynamic character of turf soils consists mostly in the relative resistance of the organic matter, which is due solely to external circumstances and not to a lack of inner energy.   For when a turf soil is exposed to favourable conditions decomposition of organic matter proceeds rapidly.   The adynamic character of turf soils is due to the joint influence of the excess of water, complete exclusion of atmospheric oxygen and the lack of the microflora essential to the decomposition of organic matter.   If, however, we drain off the surplus water without drying the sphagnum turf excessively, at the same time liming and manuring it and providing also for an artificial increase of bacteria, the most unyielding turf soil soon becomes humified—in its upper horizons at least—into a peat soil.

The bleached or *bluish grey colour* of the subsoil of moor lands, which soon turns brown on contact with the air, is attributable to reduction and leaching processes.   These processes should not be

confounded with the process (podsolisation) producing the ashen grey, bleached forest-soil layers. The latter is the result of acid leaching; while in the former case, though there is certainly leaching, the experiments of BALLENEGGER* and GLINKA† have shown that, although the reaction of the upper horizons of sphagnum turf soils is acid, in the lower horizons it becomes alkaline. This peculiar bleached layer the Russians call " gley." " Gley " is not necessarily clay or clayey; it is merely the result of the reduction and alkaline leaching processes taking place under moors. According to GLINKA not all turf soils contain a *gley* horizon, but only where the ground water has risen to the surface.‡ Therefore, though a gley horizon is characteristic of turf soils, it is not universal in them.

Chemical Characteristics.—The principal chemical characteristics of sphagnum turf soils are their low ash and plant nutrient contents, which differentiate them clearly from low-moor turfs, as we have already pointed out.

Physical Characteristics.—A characteristic property of turf soils in general is their high water-absorbing capacity. On account of its finer structure, high-moor turf has a much greater water-absorbing capacity than low-moor turf. Fresh sphagnum turf, for instance, is able to absorb a quantity of water twenty to twenty-four times its own weight; low-moor turf, on the other hand, can absorb only ten to twelve times its weight of water. It is wrong to suppose that turf is water-permeable; this is true only of turf in a dry state before it has taken up a sufficient quantity of water to make it swell. When wet, it is a bad conductor of water. The other outstanding physical property of turf soils is that they are bad heat conductors, this being the cause of the frequent damage by frost observable in early spring and late autumn. This phenomenon was previously attributed to the brown or black colour of the turf rendering its surface more sensible to temperature changes, but WOLLNY showed that in the case of drained moors the night frosts experienced in spring are due in particular to the rapid cooling of the surface—a process accelerated by the rapidity of evaporation not being counterbalanced, or only slowly, by the warmth of the deeper horizons. As another result of the poor heat conductivity, turf soils standing in water freeze even in severe winters only to a depth of 30-40 cm.

A characteristic property of turf soils is the high value of their heat of wetting (*Benetzungswarme*), as shown by MITSCHERLICH. According to data supplied by BERSCH, a comparison of the heats of wetting of turf soils with those of other soils determined by MITSCHER-LICH shows the following figures:

* See BALLENEGGER, R.: " A lápok alatt végbemenö mállásról " (Földtani Közl., 1918, Vol. XLVIII., p. 13).

† See GLINKA, K.: " Typen der Bodenbildung " (Gebr. Borntraeger, Berlin, 1914), p. 161.

‡ See GLINKA, K.: *Ibid.*, p. 160.

Heat of Wetting of 1 Gramme Soil in Gramme-Calories.

Turf soil	..	..	..	..	..	..	22·66
Garden soil	..	..	..	..	..	..	3·15
Humiferous sand	..	..	..	..	..	..	1·59
Sand	..	..	..	..	..	..	0·38
Clay soil	..	..	..	..	..	..	1·12

The high value indicated in the case of turf soil naturally varies with the kind of turf; but it deviates so considerably from the values for ordinary mineral soils that it would be worth while to employ the above figures to try to determine the line of demarcation between turf or peat and mineral soils.   Another point of interest ascertained by MITSCHERLICH is that the heat of wetting of fresh turf is less than of decomposed—humified or carbonised—turf, as is shown by the following figures:

Crude fibre	..	..	..	..	..	17·0 calories.
Brown coal	..	..	..	..	..	28·5 ,,
Humus of freshly manured soil	..	..	..	34·0 ,,
Humus of turf soil	..	..	..	..	47·0 ,,

It is quite possible that in this way we may be able to arrive at values showing the degree of humification.

Morphological Characteristics.—The deeper the mineral matter of moor land, the less does the development of the turf soil depend on that mineral matter.   The extent of this dependence must decide whether we should include a soil among the organic soils or among the soils of mixed origin.   According to WEBER's definition, *turf or peat soils in the dry state must have a layer of turf visibly free of mineral matter at least 20 cm. deep.*   If we accept this definition for the moment, we must include all soils the true turf layer of which in the dry state does not extend 25-30 cm. downwards in the group of soils of mixed origin.

Biological Characteristics.—Turf soils in general are, if we ignore the surface vegetation, biologically inactive.   This is particularly true of sphagnum turf soils, the poverty of which in nutrients in any case prevents their feeding any vegetation but mosses, which have very low nutrient requirements.

Stage V.: Sub-Types of Sphagnum Turf Soils.

It will be best to continue the classification of sphagnum or high-moor turf soils on a botanical basis.   Theoretically this may be done in two different ways: (1) by botanical analysis of the sphagnum turf, or (2) by the character of the vegetation at present living on the soil. Accepting the latter method as the simpler, and as expressing best the present dynamic conditions, we may for the moment adopt the classification suggested by TOLF:*

* See TOLF, R.: Verh. d. II. Intern. Agrogeol. Konf. Stockholm (1911), p. 170.

(1) *Sphagnum* turf soils on which the living vegetation is moss.

(2) *Sphagnum* turf soils with *Eriophorum vaginatum* vegetation.

(3) *Sphagnum* turf soils with *Scirpus cæspitosus* vegetation.

(4) *Sphagnum* turf soils overgrown with shrubs (including heath soils).

(5) *Sphagnum* turf soils covered with trees.

(6) *Sphagnum* turf soils with mixed vegetation.

(7) *Sphagnum* turf soils with lichens and mosses.

(8) *Sphagnum* turf soils with *Scirpus* and mosses.

This naturally does not exhaust the characteristics of these several sub-types. In time, perhaps, we shall have at our disposal a dynamic basis of a more satisfactory character for the further classification of sphagnum turf soils.

Stage VI.: Local Varieties of Sphagnum Turf Soils.

Details of the following local conditions are required:

(1) The local position of the soil (in order to differentiate between turf soils of depressions, valleys or hill-slopes).

(2) The prevailing, and if possible the past, hydrographical conditions.

(3) The prevailing climatic conditions.

(4) An exhaustive botanical description of the whole turf profile.

(5) A description of the mineral subsoil.

Soil Order 2: Turf Soils Rich in Bases but not Saline
(Main Type: Low-Moor Turf Soils).

Genetic Characteristics.—It is only in regions rich in nutrients that the shore vegetation that forms the low-moor soil (rushes, sedges and reeds) makes its home.

Low-moor land is usually found where the local and hydrographical conditions cause the ground water to stand continuously so high as to cover the surface of the soil. Where this only happens periodically, only water-logged meads, thickets, etc.—called "swamps" or "bogs," to distinguish them from moor lands—are formed. In swamps there is nothing to prevent a process of development of moor land; a considerable quantity of organic material becomes mixed with the mineral soil, though the result is never typical organic soil, for the vegetation of a swamp which periodically dries up dies out, and mixing with the mineral soil produces a soil of mixed origin, such as, for instance, the soil of wet meadows, which belongs to Main Group II.

When we investigate the circumstances and possibilities of formation, we find the contrast between high-moor and low-moor land to lie in the fact that the latter may occur in practically all climatic

zones—even in the torrid zones—where the ground water continuously covers the surface and is not excessively poor in nutrients; while high-moor land occurs only in the more humid and cold zones and regions. Low-moor lands reach the culmination of their development when the open water is completely grown over. From that point low-moor lands cease to develop and either change into forest moors and high moors or begin to dry up, gradually changing into meadows or swamp meadows. In these, desiccation is soon followed by a corresponding decay of organic matter, the upper turfy layer being rapidly humified, producing peat soils (in the above sense of the term) which are more or less saturated with bases (see Soil Order 5). Low-moor soils belong to this soil type, therefore, only *so long as their upper horizons in the dry state show a character corresponding to that of turf as generally described—i.e., possessing a botanical structure visible with the naked eye—to a depth of at least 25 cm.*

There are other methods of defining turf types. In Sweden, for instance, non-humified turf is defined as turf out of which, when squeezed with the hand, there oozes an almost colourless water, the turf remaining in the hand. The liquid pressed out of well-humified turf soils, on the other hand, is brown, and practically the whole of the turf material oozes through the fingers in the form of pulp. The brown liquid and the pulp both stain the hands badly, and all that can be discovered with the aid of a magnifying glass in the material left behind are a few remains of leaves or seeds.*

Here, too, it is the botanical examination of the profile that gives us the best idea of the origin of the whole turf soil.

Dynamic Characteristics.—The several layers of turf are also approximately adynamic—ectoadynamic, to use STEBUTT'S term, because external factors prevent the rapid decomposition of the turf. These factors are the excessive moisture and the complete lack of oxygen. However, as soon as the upper layer dries up, the aerobic decomposition of organic matter begins. Indeed, the process begins much sooner than in the case of high-moor turf, for low-moor turf is both looser in structure than high-moor turf and also contains more bases, thus being more favourable to the development of a bacterial flora. The formation of *gley* in the subsoil is of more frequent occurrence than it is in high-moor turfs, for the subsoil remains under water until the whole layer of turf has dried up.

Chemical Characteristics.—These characteristics have already been described when comparing them with those of high-moor turf soils. We have seen that low-moor turf soils have an ash content very much greater than high-moor turf soils. The base content is also high, and consequently low-moor turf soils are usually by no means unsaturated—*i.e.*, their reaction is not acid, but neutral or slightly alkaline.

* See HAGLUND, E.: Verh. II. Intern. Agrogeol. Konferenz, Stockholm (1911), p. 173.

Physical Characteristics.—These are, in general, the same as in the case of high-moor turf soils. There is, however, a difference; for as a consequence of their coarser structure the low-moor turf soils have a smaller water-absorbing capacity, and being worse conductors of heat they are still more liable to suffer damage by frost than high-moor turf soils.

Morphological Characteristics.—The low-moor profile is as a rule layered as illustrated in Fig. 15, in which layer *a* represents the mineral subsoil, layer *b* the organic mud at the bottom of the moor, layer *c* a sedge-turf layer, and layer *d* a reed-turf layer.

Biological Characteristics.—In these soils we do not find so much biological inactivity as in high-moor turf soils. A point particularly worth mentioning is that under favourable circumstances the nitrogen compounds in low-moor turf soils rapidly decompose, very much to the advantage of the meadow plants. There is also a much more plentiful amount of phosphoric acid, potassium and calcium for the use of the meadow vegetation. A properly drained but not excessively desiccated low-moor turf soil is soon converted into valuable meadow and pasture land much more suitable for agriculture than any high-moor turf soil.

Stage V.: Sub-Types of Low-moor Turf Soils.

For these soils TOLF has supplied the following classification of sub-types based upon differences in the living vegetation of the surface:*

(a) Grassy Low-moor Turf Soils.	(b) Mossy Low-moor Turf Soils.	(c) Shrubby Low-moor Turf Soils.	(d) Forest Low-moor Turf Soils.
A. True Forms: 1. *Carex* (sedges). 2. *Claudium.* 3. *Molinia.* 4. *Equisetum.* B. Mixed Forms: 5. Grassy and leafy meadow vegetation. 6. *Sphagnum* mixed with 1, 3 and 4.	*Hypnum* (mosses).	Shrubs and heath.	A. Deciduous Trees: 1. Birches. 2. Poplars. B. Coniferous Trees: 3. Spruces. 4. Canadian pines. 5. Mixed coniferous and deciduous trees.

* See TOLF, R.: Verh. d. II. Intern. Agrogeol. Konf., Stockholm (1911), p. 170.

Stage VI.: Local Varieties.

Here, too, we must take into account the same points as in the case of high-moor turf soils (*q.v.*).

Soil Order 3: Saline Turf Soils.

As things stand today, I am unable to characterise any definite type, since at present I do not know of any organic soil which has originated in salt water and constitutes a soil as really organic as the fresh-water turf soils. Theoretically we may, however, assume that there may be conditions tending to produce this kind of soil. The littoral, so-called " marsh " or " Kvelder " soils cannot be described as pure organic soils, as they really belong to Main Group II.—soils of mixed origin.

GLINKA,* however, notes that in the tropics MOHR found littoral
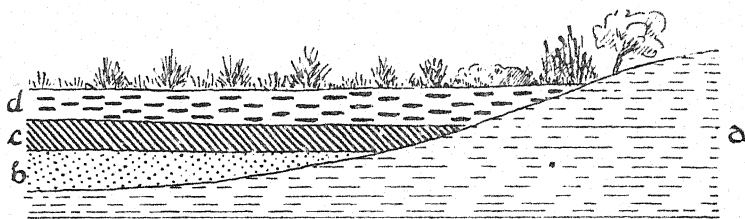
FIG. 15.

organic soils resembling our turf or moor soils. These soils occur in the deltas of rivers in places where there is an accumulation of salt water mixed with fresh water unaffected by the action of sea waves or by any silting process.

Under similar circumstances we might theoretically expect the formation of saline low-moor land, not only in the tropics but also in cooler zones. Indeed, saline low-moor land might be formed also in the interior of continents as a consequence of shallow salt lakes being grown over. I believe there can be no doubt that the low-moor lands found in alkali and saline territories include such soils, only we are not yet familiar with them.

Soil Order 4: Peat Soils Unsaturated or Acid owing to a Lack of Bases (Main Type: Acid High-moor Peat Soils).

This type of soil is in reality the *humified form* of the main type of Soil Order 1—of *Sphagnum Turf Soils*. Genetically it therefore corresponds to the latter, the only difference being that *in a layer*

* See GLINKA, K.: " Typen d. Bodenbildung " (Gebr. Borntraeger, Berlin, 1914).

of the upper horizon at least 20 *cm. in depth* (corresponding to a depth of about 30 cm. in the moist state, allowing for shrinkage on drying) *it is impossible with the naked eye to detect the vegetable structure.* This order therefore includes all the mossy peat soils which are already dead—*i.e.,* all those lands where the formation of peat has long ceased either as a result of artificial draining or by natural desicca- tion. A large proportion of the high-moor peat soils at present or at some previous period used as pastures or meadows, or actually under agricultural cultivation, are of a kind justifying us in including them among *acid peat soils* in the narrower sense of the term. How- ever, since this soil order has so far been studied rather with a view to its practical exploitation (peat production, agrarian reclamation), and in most cases not at all from a pedological point of view, I am not in a position to deal with the characteristic main type of this soil order or with its further classification, and shall therefore refer my readers for general points to the section on Sphagnum Turf Soils. What was said there may serve here too by way of general information, but as most of the peat soils under cultivation belong to this order, and as cultivation always materially changes the dynamic system of the whole soil, the cultivated acid peat soils may be grouped accord- ing to the method of improvement employed. There are methods of improvement which do not interfere with the structure of the original peat soil, merely improving the original vegetation by suit- able fertilisation, liming and the sowing of grass seeds. But this external improvement causes a whole series of internal changes. We need only think of liming and the provision of supplementary nutrients. The peat soil which was originally poor in nutrients and acid in character becomes richer in nutrients and approximately neutral. The most radical change is, however, caused by the draining off of the surplus water, a process which promotes the entry of air. This is still further increased by ploughing the upper soil and other loosening processes. Even today there are places where peat is burned. In this case, however, the utmost caution must be observed and care taken to provide that the ash and the peat residue shall combine to form a fertile layer. In other places improvement is effected by digging ditches (RIMPAU's method) and covering with sand. In many dis- tricts in Holland the intermediate peat layers suitable for use as fuel are removed, the upper barren layer being mixed with the sand of the lower layers. All these methods induce changes in the dynamic system of the original soil of such far-reaching character that it would be worth while to undertake investigations into those changes and to group cultivated peat or turf soils from that point of view, such grouping being apparently merely practical, but nevertheless pedo- logical too. For it would be a mistake to assert that soils improved in this way are not soils or at best unnatural soils. It is impossible to exclude from pedology improved soils or soils generally which have been subjected to cultivation. Human knowledge and human

ambition are also able to change and transform other natural soils so radically as to make it necessary to include them in other orders. We need only think of the improvement of alkali soils or of the liming of acid soils. This interference is not indeed so radical as that of the Dutch " legmoor system," but in time the dynamic trend of the soil ultimately changes radically even in the case of the mineral soils already referred to. The only difference is that in the case of organic soils the change is much more rapid and much more far-reaching.

Soil Order 5: Neutral or Slightly Alkaline Peat Soils Approximately Saturated with Bases
(Main Type: Neutral Low-moor Peat Soils).

These are humified soils of the main type of Soil Order 2—the Low-moor Turf Soils. On account of the richness in nutrients and bases of the original turf soil, these soils very rapidly become active under both artificial and natural conditions—viz., as soon as the overgrown meadow moor begins to dry up and gets air. Human intervention may here also induce such radical changes as to bring about a complete transformation of the original dynamics of the soil.

For other information I refer the reader to what I said about the main type of Soil Order 4.

Soil Order 6 : Saline Peat Soils.

I have nothing to add about these soils to what has been said in the case of Soil Order 3.

Soil Order 7: Endoadynamic Soils of Mixed Origin
(Main Type : Endoadynamic Skeleton Soils).

Genetic Characteristics.—This order includes those soils which have originated exclusively by physical weathering and have been deprived of the finer parts most liable to chemical weathering partly by wind action and partly by erosion. In this respect they are therefore eluvial soils. The parent material has remained in the form of boulders and gravel, as these fractions are better able to resist physical weathering than the finer fractions which have been transported. Even water does not remain on the rough boulders in sufficient quantity to cause hydrolysis of the silicates. The parent material of these soils is rock débris, gravel and quartz sand.

Dynamic Characteristics.—A characteristic feature of these soils as contrasted with others is that they are practically inactive, not because there is a lack of external soil-forming factors, but because the parent material itself is highly resistant. Consequently, skeleton soils of this kind are not confined to a certain climate or zone, but may occur in all regions where the conditions governing physical weather-

ing and wind and water erosion are favourable. Very frequently they are free of organic matter, and therefore belong to the raw soils of Main Group III. But certain plants very soon attack even the hardest rock, with the result that where the climate is humid enough to allow of the development of plants with low nutrient requirements— such as mosses and lichens—there is a certain accumulation of raw organic matter.

Chemical Characteristics.—Chemical weathering is of a very restricted character, for the minerals constituting soils of this kind— *e.g.*, pure quartz sand, quartzite sandstone—are all resistant against chemical decomposition.

Physical Characteristics.—The material of these soils is composed of skeleton particles of various sizes, from coarse sand to big boulders.

Morphological Characteristics.—These soils have no special structure.

Biological Characteristics.—In these soils only plants with very low nutrient requirements (*e.g.*, lichens and mosses) can live.

Stage V. and Stage VI.

(Sub-types and local varieties of the endoadynamic soils of mixed origin are unknown.)

Soil Order 8 : Ectoadynamic Soils of Mixed Origin (Main Type 1 : Arctic, so-called Structural Soils).

Genetic Characteristics.—These soils resemble those of Order 7 in having originated exclusively by the action of physical weathering and dynamic disintegration and are, chemically speaking, practically adynamic. The inactive character of these soils, however, which are formed in arctic climates, is due to the action of external factors. For in arctic regions the upper crust of the earth is either perpetually frozen and covered with ice, or at most periodically thaws down to a shallow depth. In the latter case we find physical weathering and also—as shown by recent researches[*]—some primitive chemical decomposition. In regions covered by eternal ice and snow there is naturally no soil formation at all; but where, in the sunny summer months, the soil thaws to some depth at least, the rock débris produced primarily by physical weathering may serve as soil for certain plants. However primitive the course of the weathering may be, the fact that the primary vegetation—the phytosphere—enters the lithosphere is in itself clear proof that soil formation has begun.

The origin of the structural soils is explained as due first to the process of re-gelation making the frozen débris push aside the coarser pieces and secondly to the particles thus separated being arranged by solifluction in keeping with orographical conditions.[†]

[*] See MEINARDUS, W.: "Arktische Böden" (Blanck's "Handbuch d. Bodenlehre." J. Springer, Berlin, 1930, Vol. III., p. 54).

[†] See MEINARDUS, W.: *op. cit.*, p. 8.

Chemical Characteristics.—It was formerly believed that in arctic soils there is no chemical weathering. However, experiments made by BLANCK* with Spitzbergen soils have shown that even in these soils there is a certain chemical change restricted almost exclusively to the oxidation and partial leaching of ferrous oxide and to the leaching of calcium and magnesium carbonates.

Physical Characteristics.—The physical arrangement of structural soils is not homogeneous, for the débris of the variously shaped boulders is much coarser than the material surrounded by them. But clay is never found, indicating that where soils of this kind occur, the weathering does not favour the formation of clay, or even if a small quantity is formed it is carried away by the rivulets created by the melting of the snow.

Morphological Characteristics.—The morphology of structural soils refers only to the surface horizon.

Biological Characteristics.—All that our inadequate knowledge enables us to state is that on the rough boulders lichens and mosses live, while the finer débris within the boulders is usually lifeless.

Stage V.: Sub-Types of Arctic—so-called Structural—Soils.

MEINARDUS distinguishes the following varieties, which we may accept as the sub-types of the main type of the structural soils:†

> *Sub-Type* 1: *Wreath- or Ring-shaped Heap of Stones.*
> *Sub-Type* 2: *Network of Stones.*
> *Sub-Type* 3: *Earth-islands scattered over Rock Debris.*
> *Sub-Type* 4: *Outcrops of Rock on Hill-Slopes.*

Stage VI.

(Local varieties of the sub-types are not yet known.)

Main Type 2 : Polygonal Soils.

Genetic Characteristics.—These soils resemble structural soils in being also surface formations occurring chiefly in the regions of eternal frost and snow or in torrid deserts. Similar polygonal soil formations may be found in other climates too, but these are either young alluvial soils (and therefore belong to Soil Order 9) or are rapidly overgrown with vegetation which effaces their original polygonal structure.

Polygonal soils owe their origin to erosion, the water carrying

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* *Ibid.*, pp. 55-64.

† In the work referred to above MEINARDUS published photographs illustrating the structural soils.

away the finer particles of the coarse débris, which it later deposits in suitable basins. When the water evaporates or freezes a finely dispersed homogeneous material is formed by the intensive shrinkage into irregular (polygonal) prisms.

Dynamic Characteristics.—These soils are adynamic because the extreme cold, the dry torrid climate, or the excessively salty or alkaline character of the soil prevents any activity.

Chemical Characteristics.—In chemical composition these soils may differ considerably. The fine mud of the arctic regions is to a large extent disintegrated rock; the salty or alkaline clay corresponds to a sodium soil, and the fine, silted deposit of torrid deserts is a mixture of mineral silt and clay.

Physical Characteristics.—As contrasted with structural soils, the mechanical composition of these soils indicates a fine texture. They are composed of homogeneous material.

Morphological Characteristics.—A characteristic feature of these soils are the polygonal cracks on the surface.

Biological Characteristics.—These soils are almost entirely lifeless. It is only in the cracks that we find plants with low nutrient requirements living—and then only for brief periods.

Stage V.: Sub-Types of Polygonal Soils.

Sub-Type 1 : Arctic Polygonal Soils.

The formation of these soils is due to the splitting action of regelation and frost. The original cracks in time become larger and deeper, while the polygonal areas protuberate.

These soils consist of inactive and barely weathered fine dust of natural origin.

Sub-Type 2 : Polygonal Soils of Torrid, Arid Deserts.

In torrid, arid deserts, too, there are occasional torrential rains resembling cloudbursts, which may cause disastrous inundations but are soon over, the fine colluvium drying quickly and then shrinking and cracking. The colluvium naturally accumulates in the shallow, closed basins of the torrid deserts. Outwardly these soils are very similar to the soils of the previous sub-type, though their origin is due to other causes and their chemical composition differs in many cases—*e.g.*, where water has transported fine mud from a place in which there has been a certain degree of chemical weathering.

Sub-Type 3 : Alkaline or Saline Polygonal Soils (e.g., the "Takir" Soils of Russia).

Genetically they belong really to the Na soils, for they are formed as colluvial surface deposits of those soils. Owing to their inactive and saline or alkaline character these soils are almost lifeless formations.

Main Type 3: Dry Tundra Soils.

The term " tundra " is used generally to denote the flat, treeless, more or less frozen regions of the arctic zones that have a covering of snow which only disappears in the warmer summer months.   The only vegetation found there is scanty, consisting of mosses and lichens. Very large tracts of land of this kind are found in particular in North and North-East Russia.*   In Russia the soils overgrown with vegetation are divided into three groups: (1) dry tundra soils, (2) turfy or peaty tundra soils, and (3) wet meadow soils.   As the two latter soil types belong to the Soil Order 10, we shall deal here only with the dry tundra soils, which, as a consequence of the prevailing climatic conditions, may be classed as undeveloped, raw soils, or as ekto-adynamic soils.

Genetic Characteristics.—In the tundra zones the average annual temperature is below 0° C., and the average annual precipitation only 200-300 mm.   The air is nevertheless humid as a result of the low temperature, and the soils often suffer from an excess of humidity. According to SOUKATSHEV,† dry tundra soils are only found on naturally well-drained plateaus.   In low-lying areas which are badly drained the soil is covered with sphagnum turf, and in river valleys with grass vegetation.

The vegetation of dry tundras is neither high nor dense.   According to SOUKATSHEV's data it consists mostly of *Carex rigida Gord* combined here and there with *Poligonum viviparum L., Festuca ovina* and a few dwarf birches and arctic willows.   The surface of the soil is covered by patches of moss some 2-3 cm. thick, this cover consisting, however, not of *Sphagnum* but of various species of *Hylocomium* and *Aulacomium*, which prefer drier soils.

Dynamic Characteristics.—Although as a result of the action of external factors the tundra soils are still undeveloped raw soils, they nevertheless show characteristic dynamic symptoms, relating them to certain wet meadow soil types.   They show signs partly of *gley* formation, partly of podsolisation, the appearance of a reduction gley horizon or of initial podsolisation respectively being apparently due to the humidity conditions of the soil.

Chemical   Characteristics. — Owing   to   the   lack   of   detailed chemical data, all we can do is to note that there is a reduction and an oxidation of iron compounds, differing in degree in the various horizons.

Physical Characteristics.—The naturally occurring soils of this type are mostly of compact, loamy structure.

Morphological Characteristics.—As we have only very few data at our disposal it is difficult to give general characteristics.   In GLINKA'

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* See GLINKA, K.: " Typen der Bodenbildung," p. 236.

† See SOUKATSHEV, W.: Ber d. Kaiserl. Akad. d. Wiss. St. Petersb··
1911.

work we find the following description of a profile based upon SOUKATSHEV's data:*

(1) Greyish-brown humiferous horizon, with slight traces of un-decomposed plant residues, 2 cm. deep.

(2) Yellowish-grey, in places greyish-brown, loose loamy horizon containing ferric oxide, 2-3 cm. thick.

(3) Greyish-blue, homogeneous, tough clay horizon, 8-10 cm. thick, with sharply defined upper and lower boundaries. A peculiarity of this soil layer is that it becomes fluid when dug out.

(4) Brownish-yellow loam, resembling horizon 2, only more com-pact, 2-3 cm. thick.

(5) Compact, brownish-grey horizon, at a depth of 40-60 cm., in many places tending to become fluid, containing here and there dark—probably humiferous—patches and in places also blocks of stone. At a depth of 79 cm. from the surface the earth was frozen, and the character of this layer remained unchanged at the bottom of the pit, at a depth of 89 cm.

Horizon 3 deserves special attention, its colour and peculiarities being, according to GLINKA, due to reduction processes similar to those accompanying *gley* formation. The thickness and development of this horizon increase with the humidity of the soil, but in sandy soils it is entirely lacking. According to GLINKA it has been found also that where there is no gley-like horizon symptoms of podsolisa-tion appear. The fluid horizon 3 is regarded as the cause of the patchy character and protuberance of the surface of tundra soils. For, if the upper horizons freeze and the lower frozen horizon is brought nearer to the surface, the fluid horizon is compressed and cools down to 4° C., at which temperature the density of water is greatest, the result being that as a consequence of the inner tension this layer comes to the surface and causes patches, or raises the sods, forming convex cushions.

Biological Characteristics.—With regard to the biological condition of these soils we have no data available beyond what has been said already.

Owing to a lack of knowledge Stages V. and VI. cannot be treated.

Main Type 4: Skeletal Soils of High Mountains.

These soils are found wherever the precipitous character of the mountains prevents the development on the steep rock-walls of any stable soil cover. At present our knowledge is too deficient to enable us to give a description of their general characteristics. All we know is that we find sporadic patches of soil types corresponding to the prevailing soil-forming factors. These patches of soil are found in

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* See GLINKA, K.: *op. cit.*, p. 173.

certain sloping or smooth places, or even in deep clefts, and show that they are really ectoadynamic raw soils; for where the orographical conditions are favourable we find soil types of normal development.

Soil Order 9: Pseudoadynamic Soils of Mixed Origin
(Main Type 1: Fresh Alluvial Soils).

Genetic Characteristics.—At certain periods or seasons the water of most rivers swells to such an extent that in flat basins it leaves the river-bed and inundates the low-lying areas in the vicinity with water and silty deposits. After the water has evaporated the mud remains, and a corresponding soil type would be formed were soil formation not disturbed by new inundations and siltings at short intervals (six to twelve months). Consequently, in places of this kind there can be no formation of an autochthonous soil profile. At the same time, we cannot say that these are only mineral débris and not soils.

Dynamic Characteristics.—The typical characteristic of fresh alluvial soils is that in them no regular changes are in evidence. Apparently they are adynamic.

Chemical Characteristics.—These vary considerably with the conditions.

Physical Characteristics.—The same is true of these also.

Morphological Characteristics.—Typical features are an irregular and very variable structure or even the absence of any structure at all.

Biological Characteristics.—These, too, may vary considerably according to differences in local conditions and in the origin of the soils.

Stage V.: Sub-Types of Fresh Alluvial Soils.

Irregular formations though the fresh alluvial soils are, we must nevertheless attempt to classify them. They may best be classified genetically according to the section (reach) of the river to which they belong, as this causes considerable differences in the quality of the sediment.

Sub-Type 1 : Fresh Alluvial Soils of the Upper Reaches of Rivers.

Here the sediment consists mostly of coarse gravel and sand mixed with only a small amount of silt. These soils are very inactive and barren.

Sub-Type 2 : Fresh Alluvial Soils of Middle Reaches.

The physical composition of these soils is usually very favourable, consisting of a mixture of fine sand and silt. Where there is still sufficient plant food in the silt and there is no shortage of moisture, these soils are covered with abundant vegetation and are very fertile.

Danger by inundation or swamp formation can be eliminated or averted by dyking, but thereby the soils sooner or later lose their character of fresh alluvial soils and change into soils corresponding to the new local conditions.

Sub-Type 3 : Fresh Alluvial Soils of Lower Reaches.

These are characterised generally by an excess of clay. The clay precipitates—particularly in estuaries where the salt sea-water acts as a precipitant—in combination with silt. These soils are therefore mostly silty clays and are not infrequently salty.

Stage VI.: Local Varieties.

The more undeveloped and raw a soil, the more effectual the action of local conditions and factors; consequently, fresh alluvial soils vary in accordance with local conditions more than soils with more or less developed profiles. The development of local varieties may be influenced by the following circumstances:

(1) The *orographical* conditions—in particular the so-called *micro-relief*. For the inundation water only gradually floods the territories at different levels, the waves washing away the higher and more elevated sections and filling up the depressions: thus, water levels the unevenness of the territory by depositing layers of silt of varying thickness on the irregular surface. The upper horizon of a fresh alluvial soil may therefore vary considerably in thickness. And when the water runs off from the slightly undulating territory, it remains longest in the deepest depressions; and if it is not absorbed by the sub-soil, and there is a natural outlet, it cuts a bed and once more transports silt. Where there is no natural outlet it dries up, and in time salts may accumulate to such an extent as to form salty or alkali soils. As this example shows, the orographical conditions may produce very great variety.

(2) The length of time during which the inundation water remains on the soil depends considerably upon the *hydrographical* conditions—particularly where the upper horizon has no natural outlet.

(3) The local *climatic* conditions also exercise an influence. It may happen, for instance, that in regions with abundant precipitation and not possessing natural outlets the flooded territories suffer much from the excessive humidity, the result being that there is a predominance of hydrophytic and swamp vegetation. In districts where there is no stagnation of water and the climate is sufficiently humid, however, we may get very fertile meadow soils or " grove soils " (*Aueböden*). In drier climates, on the other hand, we get, not meadow soils but pasture lands richer and more lasting than are found in territories with similar climates outside the inundation areas.

(4) I have already shown that the mineral and perhaps also the organic matter of fresh alluvial soils may be of very various origin;

but, as these variations affect all the fresh alluvial soils of an area, we cannot use them to differentiate local soil varieties. But variations may affect the subsoil on which the silt is deposited—particularly the water régime—according to whether the subsoil is permeable or not.

(5) A question of special importance with regard to the state of development of the soil is whether the area is one of controlled in-undation (by dykes) or a natural inundation area. For if the silting influence of water is restricted to a narrow inundation area, a thicker and more homogeneous soil layer may be formed than in the case of the periodical and irregular silting of inundation areas left to their own resources. The state of development of fresh alluvial soils is naturally always primitive; but a homogeneity of conditions favours the development of typical soils.

Main Type 2 : Shore Soil Formations of Standing Water.

Genetic Characteristics.—Where standing water occurs under tidal influence (surge, ebb and flow), on the flatter shores we may find typical soil formations. In these deposits there can be no plant life until they have accumulated sufficiently to prevent the water covering them or the waves washing them away. They are usually formed, sorted and transported, not only by the action of the waves but also by strong winds.

Stage V. : Sub-Types of Shore Soil Formations of Standing Water.

So far we know of two sub-types—shore dunes and littoral saline soils (marsh soils and kvelder soils). There are several essential differences between the two.

Sub-Type 1 : Soils of Shore Sandbanks or Dunes.

The waves throw up sand particularly on the low shores of seas; the sand is then carried by wind into the interior of the mainland until held up by some obstacle. Usually these sand waves are checked* and bound by the littoral vegetation and its underground rhizomes, only certain plants—*e.g., Ammophila arenaria, Elymus arenarius,* and species of *Carex* and *Triticum*—being able to live in the drift sand. Where a dune is not covered with vegetation the next wind carries the sand further, the dunes thus advancing, like the sandbanks found in deserts, in the direction of the wind. However, dune formations, like the drift sand of dry deserts, are usually free of organic matter and then belong to Main Group III.

Dynamically, shore dunes may be regarded as adynamic until the constant accretion of new material and their movement ceases, when they become bound by some permanent vegetation—*e.g.,* forest—and are transformed into some dynamic type.

* See RAMANN, E.: " Bodenkunde " (J. Springer, Berlin, 1811), p. 129.

Chemically, littoral sand consists of only slightly changed minerals, shells and possibly also a certain quantity of silt.

Physically, the fresh sandbank is of loose structure, though later on the action of rain may compact it. Its mechanical structure may vary considerably according to the direction of the wind and the formation of the shore.

Morphologically, sand dunes are characterised by a complete lack of structure.

Biologically, sand dunes favour the growth of the above-mentioned plants only so long as they are subjected to the action of sea-waves. When removed from the action of the sea they are very suitable for afforestation.

Sub-Type 2 : *Littoral Saline Turf Soils* (*Marsh or Kvelder Soils*).

The tidal movement of the sea—the ebb and flow—deposits on low shores silt and clay containing organic matter originating from residues of sea-animals.* We find mostly algæ, diatomaceæ, crab shells, snail excrements and indeterminable organic residues mingled with the mineral silt and clay. This marine mud is called in German *Meerschlick*. The sand deposited in the vicinity of the shore prevents the settled mud from flowing back, and there develops in the mud a certain littoral marsh vegetation (*e.g.*, *Salicornia herbacea*, *Chenopodium maritimum*, *Arenaria maritima*, etc.)† This vegetation acts with increasing effect to keep back the deposited mud, which may, indeed, even rise gradually to a height of three to four feet above sea-level. In such cases the marsh vegetation is replaced by inland vegetation (*e.g.*, *Poa maritima*, species of *Gliceria*, *Juncus*, etc.). However, since the *Meerschlick* is not rich in animal substances except in the warmer summer months, the humiferous layer is replaced by material poor in humus called *Knick* or *Kley*—not to be confused with the Russian *gley* soils.

So long as these littoral silt soils are in contact with the movement of the sea they keep receiving fresh material, and are apparently adynamic. In Holland they are called " Kvelder " soils, to distinguish them from the " Polder " soils protected by dykes.

Dynamically, they are also apparently adynamic, though not so completely as the shore dunes.

Chemically, they are weathered soils containing a certain quantity of humus-zeolite complex. Consequently, as soon as their position becomes stabilised, they are transformed into H or Na soils.

Physically, they are very clayey soils, though in their original state they are of a rather loose structure. They do not become impervious until they are cut off from the sea, when the rain water

* See RAMANN, *op. cit.*, pp. 189 and 419.
† See GLINKA, K.: " Typen d. Bodenbildung " (Gebr. Borntraeger, Berlin, 1914), p. 170.

washes out the sea salts so quickly that Ca zeolites are unable to form by interaction of the Ca salts and Na zeolites.

Morphologically, the *Knick* horizon differs from the humiferous horizons in being light in colour and impermeable. However, no typical soil structure is found except in endyked polders.

Biologically, even in their original undeveloped condition these soils are not lifeless, though the soil-forming effect of the life in them cannot assert itself, owing to the constant silting.

Stage VI.

Owing to lack of adequate information we cannot characterise local varieties.

Soil Order 10: Hydrogen Soils
(Main Type 1: Turfy or Peaty Mineral Soils).

This type includes all the formations *which are covered with a definite turfy or peaty layer less than 25-30 cm. thick.* (Peaty formations in the deeper horizons of the subsoil have no influence on the present character of the soil, and do not affect the question of its type.)

Genetic Characteristics.—These soils occur mainly in the tundra zones, but they may also be found wherever an excess of humidity does not allow the usual mainland vegetation (meadow or forest association) to develop, the only vegetation which can thrive on them being swamp plants and mosses. In this respect, the conditions of formation correspond to those of the *Sphagnum* turfs and peats. The shallow organic upper horizon, however, contains more mineral material than the true organic soils, as it is influenced by the subsoil lying near the surface. Recent data seem to suggest that the turfy soils of high mountain regions really belong to this main type.

Dynamic Characteristics.—In the turfy-peaty horizon acid humus is formed by the decomposition of the organic matter. The humus penetrates the mineral layer below partly in true solution and partly in colloidal solution. This process first mobilises the bases and then the iron, and may possibly decompose some alumino-silicate; even colloidal Al_2O_3 and SiO_2 may become mobile. Where the subsoil is dry enough, the colloids precipitate below the eluviated upper mineral horizon, in the B horizon—the horizon of sesquioxide accumulation. The organic upper horizon A is followed by the eluviated " podsol " horizon A_2.

On the other hand, where the peaty formation is due, not to an accumulation of precipitation water but to an excessive rise of subsoil water, the mineral layer underlying the organic horizon is also under water, causing the reduction processes known as *gley formation*, as already described. Accordingly, in these turfy or peaty soils there is either podsolisation or *gley*-formation—sometimes both.

Chemical Characteristics.—Chemically, the criterion of these soils is that the organic layer contains more than 25 per cent. of organic matter. The absorption complex is unsaturated in both the upper organic and the underlying mineral layer. The absorption complex consists mainly of humic acids, and the reaction is strongly acid.

Physical Characteristics.—The physical character of these soils depends partly on the degree of humification of the turfy or peaty layer and partly on the degree of unsaturation of the humus complex. The unsaturated—and therefore acid and mobile—humic acids decompose and leach out the underlying mineral layer which consequently, if clayey, does not coagulate promptly, and tends to become impervious. Where the subsoil is sand, iron pan is formed. A property common to all these soils is their high water-absorbing capacity and low permeability. In this respect they differ markedly from one of the other main types of hydrogen soils—the common forest soils of temperate climates, not infrequently found in the immediate vicinity of peaty soils. In the peaty mineral soils the water stagnates, whereas in forest soils it filters through and is carried off, or taken up by the roots of trees. Consequently, *forest soils are always drier in character than peaty mineral soils.*

Morphological Characteristics.—The turfy or peaty upper horizon differs visibly from the mineral horizons. In certain cases the upper soil horizon becomes so enriched with silt that its organic matter content falls below 25 per cent. In this case the upper horizon is practically a mineral one, though below it there is still the orginal peat or turf layer.

The morphological characteristics of the profiles of peaty or turfy mineral soils may differ considerably, but a common feature of them all is the decidedly peaty or turfy upper horizon, never exceeding 25-30 cm. in depth.

Biological Characteristics.—The biological behaviour of these soils may also vary considerably in keeping with the variations in their morphological characteristics. They are generally more active than the true organic soils, particularly where the upper horizon contains an appreciable amount of mineral matter. While the turfy horizon itself may be adynamic, it can readily be made dynamic by suitable ameliorative measures.

Stage V.: Sub-Types of Turfy or Peaty Mineral Soils.

The best subdivision of this main type into sub-types is based on dynamic variations. Since the dynamic character of the whole profile is determined partly by the organic soil horizon and partly by the mineral subsoil, we may group the sub-types as follows:

Sub-Type 1: Turfy upper horizon, *gley* subsoil.
Sub-Type 2: Peaty (humified) upper horizon, *gley* subsoil.
Sub-Type 3: Silty organic upper horizon, *gley* subsoil.

Sub-Type 4: Turfy upper horizon, podsolic sub-soil with (or without) *gley* horizon.

Sub-Type 5: As 4, but with peaty upper horizon.

Sub-Type 6: As 4, but with silty organic upper horizon.

Sub-Type 7: Turfy upper horizon, without *gley* or podsol in subsoil.

Sub-Type 8: As 7, but with peaty upper horizon.

Sub-Type 9: As 7, but with silty organic upper horizon.

Stage VI. : Local Varieties.

For the characterisation and differentiation of local varieties the following criteria are used:

(1) *Local Orographical Conditions*, which everywhere play an important rôle in soil formation. The soil's geographical situation (latitude and longitude) and its relief (plain, hill or mountain) must be taken into account.

(2) *Local Climatic Conditions.*—Although peaty and turfy soils occur in practically all climatic zones—a fact which proves that their formation is to a certain extent independent of climate—it is nevertheless indubitable that the peaty soils of arctic zones, for instance, do not show the same dynamics as the peaty soils of temperate zones or of the sub-tropics and tropics.

(3) *Hydrographical Conditions.*—The height and changes in the level of the ground water materially affect the character of the soil.

(4) *The Parent Rock* over which the peaty surface layer has been formed.

(5) *The Degree of Humification* and the state of cultivation of the soil, etc.

Main Type 2: Soils of Wet or Waterlogged Meadows.

This type includes not only the wet meadow soils occurring in the tundra zones, but also those wet or waterlogged alpine soils which have not yet become peaty, and the wet meadow soils of warmer—even arid—climates. The latter owe their formation not so much to climatic as to local orographical and hydrographical conditions. These soils occur in places where the humidity conditions are too high to permit the development of ordinary forest vegetation but not high enough for the development of peat formation.

Genetic Characteristics.—These soils represent an intermediate stage between forest and peaty soils. Genetically this is due to the soil not being humid enough to allow the domination of a hydrophyte vegetation leading to the formation of peat or turf. In this respect, therefore, this main type differs decidedly from the preceding one. The lower horizons of the soil are, however, infiltrated with water, producing conditions unfavourable to the growth of common forest trees, the so-called *acid meadow vegetation* predominating. Many scientists call

these soils *peat-like soils (anmoorige Böden)*, or include them among the mucks.* STREMME calls them meadow podsol soils,† STEBUTT‡ wet podsol soils, and FROSTERUS§ humus-podsol soils in contrast to the dry forest podsols, which in my systematics are included in Main Type 3.

Genetically, the important point is that in contrast to the forest podsols the wet meadow soils have a considerable upper humus horizon, which in forest soils exists—if it exists at all—as a very thin layer. As compared with the peaty soils the essential difference is that the humus horizon of wet meadow soils contains far less organic matter than in peaty mineral soils.

Dynamic Characteristics.—As in the case of peaty soils, the un-saturated humus of the upper horizon accumulates because under the prevailing humidity and temperature conditions more organic matter is formed yearly than is decomposed or leached out. As the ground-water level is deep enough to permit acid leaching, the acid humus of the upper horizon becomes mobile and leaches out the lower (A_2) horizon, mobilising not only the mono- and bivalent but also partly the trivalent cations. This is the origin of the ash-grey podsol horizon. The monovalent and bivalent cations leached out of horizon A_2 are often removed to a great depth, but the trivalent cations may combine with the mobilised humus and precipitate below horizon A_2, forming a normal accumulation horizon (B), unless the process is prevented by a high-water table. In the latter case a mixed BG horizon is formed—*i.e.*, an accumulation horizon in which simul-taneously the reduction processes referred to above also occur. If the ground-water level is low enough, the *gley* horizon sinks below the B horizon. Thus, below horizon A_1 (black humus horizon) acid leaching operates, while below horizon A_2 accumulation is in evidence either alone or in combination with reduction processes.

Chemical Characteristics.—We give here some data referring to the analysis of two humus podsol profiles, the first being a Finnish soil‖ (Table XLIII.), and the other (Table XLIV.) a soil from Zernez (Lower Engadine).¶

A_1:—0—15 cm. dark brown humus horizon. A_2:—15—30 cm. light grey horizon. B:—30—50 cm. dark yellow horizon. C:—>50 cm. dark-grey horizon. Vegetation: mixed coniferous forest.

Both tables show that not only the bivalent but also the trivalent

* See GLINKA, K.: "Genesis und Geographie d. russischen Böden" (Petro-grad, 1923), p. 17.

† See BLANCK's "Handb. d. Bodenlehre," Vol. III., pp. 121 and 129.

‡ See STEBUTT, A.: "Lehrb. d. allg. Bodenkunde," p. 419.

§ See FROSTERUS, B.: "Zur Frage nach d. Einteilung d. Böden in nord-westeuropäischen Moränengebieten" (Helsingfors, 1914).

‖ See STEBUTT, A.: "Lehrb. d. allg. Bodenkunde" (Gebr. Borntraeger, Berlin, 1930), p. 421.

¶ See JENNY, H.: "Hochgebirgsböden" (Blanck's "Handb. d. Boden-elhre," Vol. III.), p. 107.

TABLE XLIII

| Horizon. | Bases. | | | | | | Carbonates. | Sesquioxides. | | | SiO$_2$ % | Humus. % |
| | Alkalies. | | | Alkaline Earths. | | | | Al$_2$O$_3$ % | Fe$_2$O$_3$ % | Total. | | |
	Na$_2$O %	K$_2$O %	Total.	CaO %	MgO %	Total.						
A$_1$	1·78	2·69	4·47	1·57	0·16	1·73	—	15·29	1·98	17·27	76·42	10·9
A$_2$	1·84	2·40	4·24	0·97	0·13	1·10	—	14·52	2·05	16·57	78·01	1·3
B	3·68	4·38	8·06	0·73	0·47	1·20	—	18·19	4·78	23·00	67·65	2·3
C	2·66	4·03	6·69	0·64	0·40	1·04	—	14·06	1·95	16·01	76·17	0·0

TABLE XLIV

Soluble in HCl.	A$_1$ %	A$_2$ %	B %	C %
Al$_2$O$_3$ Fe$_2$O$_3$	—	3·99	17·00	9·70
CaO	—	0·24	0·50	10·90
MgO	—	0·34	0·37	3·73
P$_2$O$_5$	—	0·00	0·07	0·00
H$_2$O (110° C.) ..	5·41	1·20	2·00	0·81
CO$_2$	0·0	0·09	0·00	3·21
Humus	28·85	2·87	3·51	2·68
pH	6·0	6·4	6·8	7·2

bases have been partly leached out from the upper horizons, the trivalent bases having accumulated in horizon B.

The above data afford no information about the composition of horizon C or of the reduction processes—viz., the reduction of ferric to ferrous compounds, vivianite, iron sulphide and manganese oxide formation—which may all occur, and are characteristic of the *gley* horizon.

The whole profile—or at least the part above the *gley* horizon—is acid; its pH value is usually below 6·5, and its hydrolytic acidity is considerable.

Physical Characteristics.—The humus of the upper humiferous horizon disperses or dissolves readily in water or in dilute alkali solutions, the humus complex being unsaturated. Black surface soils of this kind therefore never have naturally crumbly structures, and where they are clayey they are very sticky and difficult to cultivate.

Where the parent material is sand, the solubility of the humus is greater and an aqueous solution of the soil is usually slightly coloured.

The eluvial ash-grey horizon is structureless and compact owing to its being leached and acid. As the result of accumulation the B horizon is even more compact, as is usually shown by its mechanical composition. In the case of sandy soils there is a possibility of the formation of iron pan in the B horizon.

Morphological Characteristics.—The most general characteristics of this main type are: (1) the upper horizon is acid, black or greyish-black and humiferous, but without any marked structure; (2) the more or less pronounced podsolisation as shown by the eluvial or ash-grey (sometimes almost white) podsol horizon and by the darker (brownish) accumulation horizon (B); where the ground-water level is very high, the latter may be altogether lacking; (3) the *gley* horizon, which marks the approximate high level of the water table.

Biological Characteristics.—The permanently over-humid state and acid reaction of this soil type in general favour the growth of fungi and putrefying micro-organisms. It is unlikely that there is any nitrification or nitrogen fixation, though we have no positive experimental data on that point. As a consequence of the acid leaching the upper horizons of these soils usually contain little easily soluble plant food. They are often covered with acid grasses and some representatives of peat flora; but on the sandy varieties conifers can thrive and may even form woods, provided the level of the water table is not too high.

Stage V. : Sub-Types of Wet or Waterlogged Meadow Soils.

On a basis of soil dynamics we may distinguish the following sub-types:

Sub-Type 1.—Below a considerable greyish-black or brownish-grey upper horizon an eluvial or ash-grey podsol (A_2) horizon; below that, again, a decidedly illuvial or accumulation horizon (B), followed by C and G horizons. The whole profile may therefore be designated briefly as follows: A_1, A_2, B, C, G. It does not matter if there are several G horizons in the C horizon or if the B horizon divides up into several parts (B_1, B_2); but there must not be any *gley* in the B horizon.

Sub-Type 2 : A_1, A_2, B-G, C, G.—This sub-type differs from the preceding one in that, though it has a B horizon, *gley* formation has already begun in it.

Sub-Type 3 : A_1, A_2, G.—There is no B horizon.

Stage VI. : Local Varieties.

Here too the essential criteria are the local orographical, hydrographical and climatic conditions; though the physical and chemical composition of the parent material and *the degree of development of the profile* may be used for characterising the local varieties.

Main Type 3 : Common Forest Soils of Temperate Zones.

These soils the Russians call *podsolic*, though the typical ash-grey (podsol) colour is in many cases not apparent at all. However, since podsolisation also takes place in wet meadow soils, we may call these soils *dry podsolic*, to distinguish them from the meadow soils, though it should be noted that in comparison with the types of Soil Order 11 they are humid. The soils now being discussed form the majority of HILGARD's humid soils. From the general structure of their profiles we may symbolically designate them ABC soils, *adding, however, that they are hydrogen soils*, since ABC soils are also found among the sodium soils.

Genetic Characteristics.—GLINKA includes these soils among those formed under moderate humidity conditions.* He points out also that the reason why the ash-grey podsolic soils are identified with the forest soils is that the majority of podsolic soils are found in forest zones.

DAUBRÉE (1775-80), KINDLER (1836) and SPRENGEL (1837) detected the character of the eluviated ash-grey horizons which Russian scientists call *podsols* (*zola* in Russian means *ash*), and from whose colour the podsolic soils are named. Podsols are formed really by the action of the raw humus or acid humus cover. Consequently no podsolisation can take place except in a climate in which raw humus is formed. Now, since raw humus covers are formed mostly in closed conifer or deciduous forests, podsolic soils occur zonally in those climatic zones in which there is a natural predominance of closed forests. No typical podsol horizon can form below the vegetation litter and mild humus cover of open forests; nevertheless, a certain fading of the colour of the horizon below the humus layer is often apparent, for which reason these soils are also spoken of as podsolic or podsol-like. We may therefore group in the main type of podsolic soils all the forest soils of temperate zones with humus covers—*with the exception of those " brown earths " in which the podsolic horizon is replaced by an accumulation horizon of brown ferric oxide hydrate*, and which, according to STEBUTT and RAMANN, are products of weathering induced by carbonic acid (see Soil Order 13). Podsolic forest soils are found, however, not only in temperate but also in warmer and more humid climates. According to VAGELER, podsolic soils are also found in the tropics, although the forest soils there are mainly laterites. But, whereas in the humid temperate zone these soils are found zonally, in other climatic zones they occur only in special regions or as local formations. JENNY† gives the following rain factors (LANG system) and N-S-Q values (MEYER system) for the posdolic forest soils and brown forest earths respectively:

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* See GLINKA, K.: " Typen d. Bodenbildung." p. 66.
† See JENNY, H.: Soil Research, Vol. I. (1929), p. 170.

	Podsolic Forest Soils.	Brown Forest Earths.
Lang's rain factor ..	Europe, 100-300 U.S.A., 114-198	Central Europe, 60-80 U.S.A., 80-100
Meyer's N-S-Q value ..	Europe, 400-1,000 U.S.A., 377-750	Central Europe, 275-400 U.S.A., 320-460

Dynamic Characteristics.—STEBUTT calls the dynamics of podsolic soils destructive, meaning that no zeolite complex is formed during weathering, as the acid humus prevents its formation and decomposes any previously formed. The absorption complex of podsolic soils is, indeed, usually far less than that of calcium or sodium soils.

The fact that in the absorption complexes of these highly acid soils we usually also find exchangeable aluminium, which must have originated from previous decomposition of the zeolite complex or the original silicates, and occurs as a cation in the outer shell of the absorption complex, also supports the assumption that in an acid medium hydrogen ions not only exchange the bases but decompose the zeolite complex into SiO_2 and Al_2O_3 gels. Actually, small quantities of SiO_2 and Al_2O_3 soluble in weak alkalies and indicating the presence of free silicic acid and aluminium hydroxide gels are found in acid forest soils.

We may therefore safely conclude that there is only a slight inorganic complex in the absorption complex of podsolic soils and that even that will sooner or later be decomposed. The bulk of the absorption complex is a humus complex, which disperses readily as the absorbed cations are mainly hydrogen. The humic acids formed in the humus layer move downwards, leaching out from the upper horizons (A_1 and A_2) first the mono- and bivalent and afterwards some of the trivalent cations. The leaching of the iron oxide gels by the protective action of the humus colloids results in the upper horizon, as a whole, losing colour, the lower part of the A horizon (the so-called A_2 horizon) often becoming quite whitish-grey or ash-grey.

The colouring materials rendered mobile by the humic acid then precipitate in the lower horizons, where there is less moisture and more bivalent cations. First the humus emulsion breaks up and precipitates, destroying the stabilising effect of the protective colloids, while the Fe_2O_3, Al_2O_3 and SiO_2 dispersions also gradually coagulate. Thus, below the colourless A_2 horizon there is formed first a brownish-black and then a rusty-brown iron horizon. When the parent material of the subsoil is loose enough (sand) and the soil in the deeper sections in which the roots of trees are present is dry enough, the coagulation of the colloidal dispersions takes place *en masse* and so suddenly that the precipitated colloids (in particular the Fe_2O_3) cement the loose material. This is the origin of the formation of iron ores and iron

concretions (*Ortstein*).   This cementing process in the subsoil of sandy soils may be intensive enough to form completely impervious hard pans.   A soil profile of this kind is illustrated in Fig. 16.

In the case of a more compact subsoil—or where the high level of the ground water prevents such a precipitation *en masse*—there is no formation of iron ore, only the rusty colour of the subsoil indicating an accumulation of ferric hydroxide.   Finally, there are cases in which neither the A horizon nor the B horizon is visible with the naked eye;
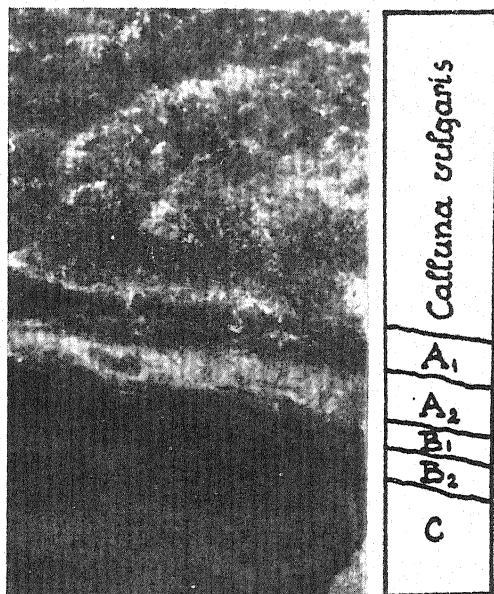
FIG. 16.—PODSOLIC SOIL WITH HUMUS AND IRON ORE.

Photo by ZUCKER.   From Paa, in Jutland, Denmark.   A₁: 0-14 cm., humiferous, dark grey horizon.   A₂: 14-30 cm., light grey podsol horizon.   B₁: 30-37 cm., dark grey humiferous iron ore.   B₂: 37-43 cm., reddish-brown iron ore, poor in humus.   C: from 43 cm., coarse yellow sand subsoil.

only chemical analysis of the soil points indisputably to the results of soil leaching in an acid medium.

In soils acidified by unsaturated humus, decomposition of silicates is also active.   The acid humus is a colloidal dispersion in the outer ion-shell of which there are many H ions.   This naturally considerably increases the H-ion concentration of the soil solution and thereby accelerates silicate decomposition, *the effect being similar to what would be produced by continuously filtering through the soil profile a weak acid of similar H-ion concentration*.   The easily decomposable and soluble phosphoric acid, potassium, calcium and magnesium are also leached out of the upper horizons, only the less soluble plant foods remaining

in the soil. This process in itself involves no danger to the forest, for the roots of the trees derive the plant food they need from lower horizons and the quantity required is much less than that required, for instance, by grasses or ordinary cultivated plants. It might even be said that this process assists the nutrition of the trees, as the deeper roots of the trees can recover the plant foods lost by leaching. In this way, therefore, there may develop a *closed circuit* which *ensures a continuous supply of nutrients* despite the fact that the acid-leaching process is also continuous. The situation changes completely, however, when we replace the natural forest vegetation with artificially cultivated vegetation. Such *cultivated soils are usually poor in plant food and in constant need of fertilising.*

Chemical Characteristics.—There are hardly any soil types for which more chemical data exist than for the forest soils of temperate zones. But owing to the considerable differences between the variously podsolised soils it was long before the chemical characteristics of this soil type were satisfactorily determined. In particular, the investigations of EMEIS,[*] MÜLLER[†] and RAMANN[‡] threw light on the chemical composition and the relation to the parent rock of the two striking horizons of podsolic soils—viz., the eluviation horizon or ash-grey soil (German: *Bleicherde, Bleichsand, Bleisand* ; Russian: *Podzol*) and the iron-ore horizon (German: *Orterde, Ortstein, Branderde, Fuchserde, Ahl, Knick,* etc.).

TABLE XLV

Podsol Soil formed on Granite, Total Analysis by Fusion.

	A_1	A_2	B	C
	%	%	%	%
Moisture	3·06	1·69	4·10	0·98
Humus	10·94	1·25	2·29	—
Loss on ignition ..	12·78	5·02	6·00	1·21
SiO_2	66·86	74·01	63·60	74·87
Al_2O_3	13·38	13·78	17·10	13·82
Fe_2O_3	1·71	1·95	4·50	1·92
Mn_3O_4	0·04	0·04	0·08	0·04
CaO	1·38	0·92	0·69	0·63
MgO	0·14	0·13	0·45	0·40
K_2O	2·36	2·28	4·12	3·96
Na_2O	1·56	1·75	3·46	2·62
Total ..	100·21	99·88	100·00	99·47

[*] See EMEIS, C.: "Waldbauliche Forschungen und Betrachtung," Berlin, 1876.
[†] See MÜLLER, P. E.: "Studien über die natürlichen Humusformen, usw.," Berlin, 1887.
[‡] See RAMANN, E.: "Bodenkunde" (J. Springer, Berlin, 1911).

A few characteristic data will be found in Tables XLV. and XLVI.*

These data show clearly that the cultivated layer is characterised by an accumulation of total SiO_2 at the cost of other constituents. The iron-ore horizon, on the other hand, is characterised by an accumulation of Fe_2O_3, Al_2O_3 and humus.

As an example of strong podsolisation STREMME supplies data showing the chemical composition of the profile of a forest soil formed on the granite of the Nürnberg Schwarzwald† (Table XLVI.), the analyses being by HELBIG and MÜNST. The soil profile is divided into horizons A_1, A_2, B_1, B_2, B_3-C. Of these, A_2 is the true podsol horizon, B_1 being the iron ore and B_3-C the weathering horizon of the granite débris out of which the soil profile was formed by a conifer forest at least 150 years old. The undergrowth consists of a few ferns and mosses.

TABLE XLVI

	A_2 Horizon.			B_1 Horizon.			B_3-C Horizon.		
	Total by Fusion.	Dissolved by HCl.		Total by Fusion.	Dissolved by HCl.		Total by Fusion.	Dissolved by HCl.	
		Helbig's Data.	Münst's Data.		Helbig's Data.	Münst's Data.		Helbig's Data.	Münst's Data.
	%	%	%	%	%	%	%	%	%
SiO₂ ..	81·46	0·10	1·01	62·83	2·21	5·82	69·61	0·12	5·17
Al₂O₃ ..	10·22	} 1·54	0·68	18·56	12·26	9·88	15·24	} 8·15	5·55
Fe₂O₃ ..	1·38		0·54	4·80	1·57	1·76	2·33		2·16
MnO ..	0·11	0·11	—	4·14	0·56	—	1·12	0·24	—
CaO ..	0·17	0·12	0·03	0·78	0·18	0·09	0·97	0·20	0·06
MgO ..	0·57	0·06	0·03	0·63	0·34	0·29	0·69	0·14	0·37
K₂O ..	0·90	0·09	0·07	4·48	0·21	0·29	5·20	0·22	0·27
Na₂O ..	3·64	0·12	0·02	4·63	0·16	0·11	5·47	0·05	0·09
P₂O₅ ..	0·29	0·03	0·16	0·89	0·13	0·74	0·58	0·09	0·47
SO₃ ..	—	0·05	0·01	—	0·26	0·07	—	0·05	0·03
Total	101·74	2·21	2·76	101·73	18·07	19·05	101·21	9·26	14·07
TiO₂ ..	0·04	—	—	0·02	—	—	—	—	—
Loss on ignition	8·28	9·10	—	35·20	38·17	—	10·32	11·33	—
H₂O (105° C.)	1·36	2·71	—	10·06	13·89	—	2·90	4·81	—
H₂O ..	—	4·07	—	—	23·68	—	—	9·22	—
C ..	—	3·47	—	—	10·80	—	—	2·55	—

* See GLINKA, K.: " Die Typen der Bodenbildung " (1914), p. 77.
† See BLANCK's " Handb. d. Bodenlehre," Vol. III., p. 150.

This table is of particular interest, as it includes data both of the total fusion analysis and of the hydrochloric extract.

First let us take the data of the fusion analysis. Very striking is the *considerable accumulation of SiO_2 in horizon A_2*. B_1 on the contrary contains the least SiO_2. The *maximum content of the sesquioxides $(Fe_2O_3 + Al_2O_3)$ occurs in horizon B_1*, the horizon A_2 being poorest in them. This means that the sesquioxides (including also MnO) have been intensively leached out of the upper horizons and for the most part precipitated in horizon B_1. Of the three horizons investigated the total carbon content of horizon B_1 was the largest, indicating an accumulation of organic matter.

The maximum values of the alkalies and alkaline earths (K_2O, Na_2O, CaO, MgO) are found in the lower (B_3-C) horizon, and the minimum values in the A_2 horizon. This shows clearly that these constituents, very mobile in an acid medium, are leached out into deeper horizons than the sesquioxides. The phosphoric acid is also, it would seem, precipitated at least partly in combination with the sesquioxides and accumulates in horizon B_1. In this soil profile the titanic oxide (TiO_2) is a very subordinate constituent, but in soils richer in titanic oxide we have found that it behaves in the same way as the silica— *i.e.*, it accumulates in the upper horizon.*

The fusion analysis only gives rough information as to the total amounts of the parent material leached out by the acid medium and precipitated in the lower horizons. *We cannot, however, determine the actual eluviation and accumulation except by a study of the hydrochloric extract, the absorption complex and the water extract.*

HELBIG's and MÜNST's data for the hydrochloric extract were obtained from the analyses of two different profiles of the same soil; nevertheless, when we compare the two sets of data, the general picture is the same, only the absolute values being different—a circumstance which may be due to the two analysts having employed different methods of solution.

If we first compare only the chemical characters of the hydrochloric extract, we find that in general *the part decomposed and dissolved by hydrochloric acid is considerably smaller in horizon A_2 than in the* parent rock, and *much less than in horizon B_1. This fact shows clearly the downward migration of the weathered part and its accumulation in horizon B_1*. In contrast to the fusion analysis we see that not only the sesquioxides and the MnO soluble in hydrochloric acid, but also the soluble SiO_2, MgO, P_2O_5 and SO_3 are accumulated in horizon B_1. It is evident, therefore, that the silicic acid of the weathered silicates is also to a large extent leached out of the upper horizon by the action of the acid medium. Furthermore, the phosphates readily decomposable by acids accumulate in horizon B_1, while the CaO and K_2O are washed through.

When we compare the chemical character of the hydrochloric
_____
* See BLANCK's "Handb. d. Bodenlehre," Vol. III., p. 148.

extract with the result of the fusion analysis, we see that the latter does not show the partial leaching of the silicic acid; on the contrary, we find an accumulation of SiO_2, to be explained by the accumulation of quartz. In the hydrochloric acid extract this accumulation is reflected in the increase in the insoluble residue. I consider, therefore, that the fusion analysis can be dispensed with; the exact composition of the insoluble mineral residue, if required, can be obtained by direct analysis.

The leaching phenomena described above occur not only in typically developed forest-soil profiles, but also in those in which the podsolic horizon is hardly perceptible or not visible at all with the naked eye. *A chemical examination of the soil, even in the case of doubtful profiles, reveals the familiar symptoms of acid leaching.*

Now let us see the manner of development of the absorption complex of forest soils. The mixed deciduous forest (sessile oak and birch) at Hüvösvölgy (Budapest) supplied the soil profile the hydrochloric acid extract analyses of which have been given in Table XVI.

In Table XLVII. are given the total mg. equivalents of the cations and the equivalents of each cation and anion calculated as a percentage of the total cation equivalents.

The total mg. equivalents of the cations are appreciably less in horizon A than in horizons B_1, B_2 and C, indicating very considerable leaching. If, in the case of the C horizon, we deduct a percentage of equivalents corresponding to the

Fig. 17.

FOREST SOIL PROFILE UNDER MIXED DECIDUOUS FOREST IN THE HÜVÖSVÖLGY, NEAR BUDAPEST, TAKEN BY DR. J DI GLERIA.

carbonates (42 per cent. CO_3), we get roughly 400 mg. equivalents for the silicates, again showing that a considerable proportion of the cations (Al_2O_3, Fe_2O_3) originating from the silicates has accumulated in horizons B_1 and B_2.

In the case under discussion the CO_3 equivalent in the original loess soil represented 42 per cent. of the total anion equivalents. Indeed, when we take into account the 9·20 per cent. oxide remainder representing additional cation equivalents, the percentage of SiO_4

equivalents represents only 47·18 per cent.—*i.e.*, barely one-half of the original rock—whereas in the A and B horizons of forest soils the percentage of SiO_4 equivalents ranges from 97 to 98 per cent. This illustrates numerically the intensive decomposing and eluviating effect of acid leaching on the formation of the soil.

TABLE XLVII

Horizon.		A	B₁	B₂	C
Sum of Cation Equivalents in 100 g. Soil.		376·52	523·26	696·39	865·75
Percentage of Equivalents calculated to the Sum of Cation Equivalents.	Na^I	3·32	2·53	2·03	1·3
	K^I	3·20	2·39	1·55	1·5
	Ca^{II}	5·67	13·06	8·55	37·39
	Mg^{II}	10·56	7·68	8·82	20·30
	Mn^{II}	2·10	2·97	0·28	3·10
	Fe^{III}	15·85	18·69	15·91	15·02
	Al^{III}	59·30	52·68	62·85	20·79
	SO$_4$^{II}	2·16	1·10	1·40	0·87
	PO$_4$^{III}	0·68	0·85	0·80	0·59
	CO$_3$^{II}	—	—	—	42·16
	SiO$_4$^{IV}	97·16	98·05	97·80	47·18
	O^{II}	—	—	—	9·20

(The first group of seven cations for horizon C is braced to total 100; the lower group of five for horizon C is braced to total 100.)

TABLE XLVIII

Horizons.	Exchangeable Cations expressed in mg. Equivalents in 100 g. Soil.					
	Al	Ca	Mg	Na	K	S = Sum
A	0·9	4·61	6·27	0·64	2·20	14·62
B₁	0·7	6·96	5·21	1·24	2·12	16·23
B₂	0·5	10·66	3·5	1·37	2·53	18·56
C	—	16·32	3·2	1·68	2·10	23·30

Horizons.	Percentage of Cation Equivalents, calculated to S-Value = 100.					
	Al	Ca	Mg	Na	K	
A	6·1	31·5	43·0	4·4	15·0	—
B₁	4·3	43·0	32·0	7·7	13·0	—
B₂	2·7	57·4	18·8	7·7	13·7	—
C	—	70·0	13·7	7·2	9·1	—

In Table XLVIII. the exchangeable cations are expressed in mg. equivalents and in percentages of all the equivalents (S).*

It will be seen that among the exchangeable cations in horizon A magnesium equivalents predominate, but decrease continually with the depth, while the calcium equivalents increase. The proportion of sodium equivalents is smallest in the upper horizon, increasing with the depth. The absolute quantity of potassium equivalents is practically constant, but as compared with the other cations it is relatively the highest in horizon A, decreasing with the depth. Special attention is due to the exchangeable aluminium, which must have penetrated into the so-called outer shell of the absorbing complex as a result of the partial decomposition of the zeolite complex due to the acid reaction of the soil. Other authors, too,† have found exchangeable aluminium in acid soils. This confirms the hypothesis of GEDROIZ and STEBUTT that in the case of acid humus the anion part of the zeolite complex may be partly decomposed too. DI GLERIA found that part of the SiO_2 and Al_2O_3 was directly soluble in a 5 per cent. KOH solution:

| | | | | Soluble in 5 Per Cent. KOH. | |
Horizon.				SiO_2 Per Cent.	Al_2O_3 Per Cent.
A	..	..	..	..	1·57	0·60
B_1	..	..	..	..	2·02	0·48
B_2	..	..	..	..	1·90	0·46
C	..	..	..	..	1·51	0·46

These data also confirm the hypothesis that insoluble colloidal SiO_2 and Al_2O_3 may occur independently.

The amounts of the exchangeable mono- and bivalent cations in the hydrochloric extract are shown in Table XLIX. expressed in mg. equivalents and in percentages of the total amounts of each cation dissolved.

It will be seen that the exchangeable cations constitute only a small percentage of the cations soluble in HCl. From this it follows that *from the silicate complex reconstructed from the bases in the hydrochloric extract, we cannot—as* GANSSEN *did—ascertain the state of saturation of the soil.* This can only be done by direct determination of the absorbed hydrogen.

The state of saturation of the absorbing complex of forest soils can be seen from Table L., giving data relating to a so-called wet siallitic soil (St-4) from Santander in Spain and to a xerosiallitic forest soil (Md-52) from Madrid. The soils were supplied by DEL VILLAR‡ and were analysed by my assistant, Dr. L. Kotzmann. It should be

* See SIGMOND, A. A. J. VON: Proc. Papers I. Int. Cong. Soil Sci. Wash., Vol. I. (1927), p. 60.

† See KELLEY, W. P.: Univ. Calif. Publ. Techn. Pap. 15 (1924), p. 19.

‡ See VILLAR, E. H. DEL: "Les sols méditerranéens étudiés en Espagne" (Madrid, 1930), pp. 50 and 144.

noted that the Santander subsoil contains 88 per cent. CO_3 equivalents—*i.e.*, roughly 70 per cent. carbonates—nevertheless, in the humid and warm climate of Santander horizons A, B_1 and B_2 are free of carbonates. In the absorbing complex, however, there is a considerable quantity of calcium cations.

TABLE XLIX

Cations.	Horizons.	Total mg. Equiv. dissolved in HCl.	Exchangeable mg. Equiv.	Percentage of Exchangeable Equiv. to the Total.
Ca ..	A	21·4	4·61	21·75
	B_1	68·2	6·96	10·20
	B_2	59·6	10·66	17·85
	C	320·0	16·32	5·10
Mg ..	A	39·76	6·27	15·77
	B_1	40·21	5·21	12·95
	B_2	61·42	3·50	5·69
	C	175·75	3·20	1·82
K ..	A	12·10	2·20	18·18
	B_1	12·52	2·12	16·90
	B_2	11·82	2·50	21·40
	C	12·95	2·10	16·20
Na ..	A	12·58	0·64	5·08
	B_1	13·93	1·24	9·38
	B_2	14·20	1·37	9·65
	C	11·30	1·68	14·85

TABLE L

Soil.	Horizons.	Absorbed mg. Equiv. of H.	Sum of the Absorbed Cations. S	Absorbing Capacity of the Soil. T	Degree of Saturation of the Soil. $V = \frac{S}{T} 100.$	Percentage of Exchangeable Cations calculated to T=100.				
						Ca	Mg	K	Na	H
Soil of Santander, St·4	A (I.)	7·74	17·39	25·13	69·19	63·27	3·30	0·99	1·63	30·81
	B_1 (II.)	7·03	28·03	35·06	79·95	76·18	1·60	0·66	1·51	20·05
	B_2 (III.)	5·76	36·51	42·27	86·37	81·48	3·76	0·73	0·40	13·63
Forest soil, Madrid. Md·52.	(S)	10·57	12·94	23·51	55·04	46·87	3·32	2·04	2·81	44·96
	A (I.)	5·66	8·17	13·83	59·08	47·00	5·93	2·53	3·62	40·92
	B_1 (II.)	13·64	16·62	30·26	54·92	47·16	4·69	0·69	2·38	45·08
	B_2 (III.)	1·42	6·18	7·60	81·31	75·53	—	1·45	4·34	18·68

The Madrid forest soil was formed on carbonate-free sand, and hydrogen has been better able more completely to expel the calcium cations from the absorbing complex.

The composition of the water extracts of both soils is shown in Table LI.

TABLE LI

Soil.	Horizons.	Total Dry Matter.	Residue of Ignition.	Dissolved from 100 g. Soil.						
				HCO_3	Cl	SO_4	CaO	MgO	K_2O	Na_2O
				Milligrammes.						
Soil, Santander, St.4.	A (I.)	268	140	25·2	4·9	—	5·0	5·9	3·1	11·6
	B_1 (II.)	134	76	12·6	5·7	5·7	2·7	5·0	3·1	9·9
	B_2 (III.)	154	70	18·8	3·5	8·9	3·3	3·4	6·3	10·2
Forest soil, Madrid, Md-52.	A_0	76	26	18·9	3·2	8·4	2·9	15·0	5·2	5·6
	A (I.)	66	20	17·0	3·5	22·0	1·7	17·4	6·1	6·9
	B_1 (II.)	54	20	12·6	2·8	12·3	1·3	16·5	3·1	8·6
	B_2 (III.)	46	46	26·4	5·3	15·9	0·6	15·3	2·9	11·3

The first thing that strikes us is the small amount of the water-soluble materials, consisting mainly of organic matter in the upper horizons. The HCO_3 content is formed not from original carbonates, but by the action of the slight CO_2 content of the distilled water. The small amount of the calcium cations—particularly in comparison with the sodium and the magnesium—is striking, and becomes still more so if we calculate the cation equivalents, as in the case of the absorbing complex, in percentages of the total amount of cations, as may be seen from Table LII.

These data show clearly that in the water extract of the forest soils the calcium cations are quite insignificant, Na and Mg predominating. This, of course, does not necessarily apply to all forest soils, but the proportion of calcium cations in their water extracts is usually very much less than in calcium soils—a fact connected with the stability of colloidal dispersions in forest soils.

Physical Characteristics.—The mechanical composition of forest soils may vary greatly, for forests can develop not only in gravelly or sandy, but also in clayey soils. The clay fraction and humus of the heavier forest soils, being unsaturated, are deflocculated and sticky.

If we submit to mechanical analysis the various horizons of a forest-soil profile, we very often find that in the B horizons the finer particles have accumulated at the cost of the A horizon, as may be seen from

the figures of Table LIII., which contains data for three forest soils collected by BALLENEGGER.*

TABLE LII

Soil.	Hori-zons.	Percentage of Cation Equivalents, calcu-lated to Total of Cations = 100.				Total Cation Equiv. in mg.	Percentage of Anion Equiva-lents, calculated to Total Cations = 100.			Total Anion Equiv. in mg.	Per-centage Deficit of Anion Equiv.
		Ca	Mg	K	Na		HCO$_3$	Cl	SO$_4$		
Santan-der, St·4.	A	19·8	31·9	7·7	40·6	0·91	45·05	15·38	—	0·55	39·37
	B$_1$	12·3	34·3	9·6	43·8	0·73	28·77	21·92	19·18	0·51	30·13
	B$_2$	16·0	22·7	17·3	44·0	0·75	41·33	13·33	29·33	0·63	16·01
Madrid, Md·52.	A$_0$	8·8	65·6	9·7	15·9	1·13	27·43	7·96	18·58	0·61	46·03
	A	4·7	67·8	10·2	17·3	1·27	2·05	7·87	43·31	0·93	26·77
	B$_1$	4·1	67·2	5·7	23·0	1·22	17·21	6·55	25·41	0·60	50·83
	B$_2$	1·7	63·3	5·0	30·0	1·20	35·83	11·66	33·33	0·97	19·18

TABLE LIII

Name of the Soil.	Horizons.	Diameter of Particles in mm.			
		2·0-0·2	0·2-0·02	0·02-0·002	< 0·002
Tenke, com. Bihar, Hungary.	A	9·0	42·8	26·8	21·4
	B	5·4	29·5	23·4	41·7
	C	13·9	36·8	39·9	19·4
Kisunyom, com. Vas, Hungary.	A	13·8	47·8	21·6	16·8
	B	9·7	39·3	19·9	31·1
	C	10·9	35·0	27·0	27·1
Nagykanizsa, com. Zala, Hungary.	A	2·3	57·8	22·6	17·3
	B	1·0	45·8	24·0	29·2
	C	1·1	53·3	24·8	20·8

BALLENEGGER examined also the plasticity of the upper horizons, using ATTERBERG's method, and found that all three soils belonged to ATTERBERG's sub-group of loamy clay soils.

Morphological Characteristics.—The chief characteristic of forest

* See BALLENEGGER, R.: "Magyarországi talajtipusok mechanikai vizgá-latának eredményei" (1915 Report of Hungarian Geological Institute).

soil profiles is the difference in colour between the three main horizons (A, B, C). The A horizon is the eluvial horizon beneath the humus cover; it is whitish-grey or brown, more or less compact, of laminar or platy structure, and when fully developed may be divided into three parts—viz., the A_0 horizon, the raw humus cover formed from the fallen forest leaves, usually 1-4 cm. thick; the A_1 horizon, sharply distinct from the humus cover, its humus content having infiltrated from the humus cover and its colour being therefore darker than the lower and more completely leached-out part of the A horizon (the A_2 horizon). The latter in the case of well-developed podsol soils is ash-grey or whitish-grey; it has no definite structure, though its lighter colour distinguishes it sharply from the B horizons below it. Even in only slightly podsolic soils we can usually observe the lighter shade.

The A horizons are followed by the illuvial B horizons, in which—owing to the partial precipitation and accumulation of colloidal dispersions—the colour of the soil is darker and its structure nutty or prismatic. The darker colour originates from the precipitated humus and iron hydroxide dyeing the mineral material a blackish-brown or dark-brown. It is often possible to differentiate by differences in colour and structure several sub-horizons in the B horizon—viz., B_1, B_2 and B_3.

The lower part of the B horizon, unless it contains a decided iron-ore layer, very often gradually passes over into the parent rock. This transitional horizon is often marked B-C or B_2-C or by some similar symbol.

In the C horizon we also often find accumulations, such as $CaCO_3$ concretions, which have been leached down from the upper horizons. $CaCO_3$ concretions are naturally found only in those forest soils the parent rock of which was originally calcareous. In such cases the C horizon itself is also divisible into several sub-horizons—e.g., an upper part containing calcium concretions (C^{Ca}) and the original calcareous C horizon (CCa).

We may therefore characterise the different varieties of forest-soil profiles by the following symbols:

	A		A_0
A	A	A	A_1
	A		A_2
	B_1		B_1
B	B_2	B	B_2
	B_3		B_3
C	C_1		C^{Ca}
	C_2	C Ca	C Ca
On parent rock free of carbonates.		On calcareous parent rock.	

The above symbols show only the simplest and most detailed articulation respectively; in nature there may be many variations in the intermediate horizons.

Biological Characteristics.—The biological characteristics of forest soils have been fully described by several investigators, especially by Professor FEHÉR.* In forest soils in general the microflora varies according to the degree of solar radiation. The maximum quantity of bacteria is found in summer and the minimum quantity in winter. The relative proportion of anaerobes as compared to that of aerobes is small; and the anaerobes do not show so great a fluctuation as the aerobes, though in the case of the former the maximum and minimum coincide with the maximum and minimum respectively of the total and the aerobic bacteria.

The fact that in forest soils the aerobic microflora so completely dominates the anaerobic would appear to be a further confirmation that forest soils cannot be included among the soils suffering a shortage of air as a result of an excess of humidity—in the category to which, for instance, the wet meadow and the turf or peat soils belong. Nevertheless, the fact that generally speaking the number of nitrifying bacteria is materially below that of the denitrifying bacteria, while the number of nitrogen-fixing bacteria is relatively small and that of butyric-acid bacteria is considerable, justifies our supposing that periodically the conditions in forest soils may favour reduction processes.

The microflora of forest soils is closely connected with the higher vegetation. The falling leaves of the trees supply the bacterial flora with nutrients, while the bacteria in their turn feed the foliage of the trees with CO_2 and the trees with nitrogen resulting from the decomposition of organic matter. There is thus a constant circulation of carbon and nitrogen between the microflora and the macroflora of the soil. FEHÉR'S investigations show that the maximum production of CO_2 practically coincides with the maximum number of total bacteria—*i.e.*, it occurs in the summer months.

The forest's N requirements are secured by the circuit referred to above, and the mineral food is supplemented by the slow but constant decomposition of the parent rock. The mineral origin of a soil— *i.e.*, the composition of the parent rock—is therefore very important for the quality of the forest. The plant food demands of the various species of trees vary considerably; and as the easily soluble nutrients are continuously leached out in an acid medium, where the parent rock itself is poor in plant food, the soil also is poor and is only able to grow trees which are satisfied with a scanty supply of food. Under natural conditions this circumstance, combined with the prevailing climate, in effect selects the kind of forest most suitable to the conditions; and until these circumstances are disturbed by some natural or artificial change, the forest thus formed lives, develops and regenerates—in a word, becomes permanent. But if the pedogenetic process is diverted by the formation of peat in certain parts of the forest, or if the forest

* See FEHÉR, D.: Erdész. Kisérl., Vol. XXXI. (1929); FEHÉR, D., and VARGA, L.: *ibid.*; FEHÉR, D.: Erdögazd. Szle., 1930, Nos. 1-3; FEHÉR, D.: Arch. Mikrobiol., Vol. I. (1930), pp. 381 and 464.

is burnt or is destroyed, or if the land is put under cultivation, the original equilibrium is upset and a new and mobile equilibrium forms in its place. Thereby the biological balance of the whole soil is naturally also modified in keeping with changes in the dynamic system of the whole profile, and a soil metamorphosis ensues, the character and results of which are determined by the new circumstances. From the point of view of systematics, however, the soil remains a forest soil so long as it shows traces of the original characteristics—*i.e.*, even where the forest flora has perished either by natural or artificial means.

From the point of view of soil systematics the only criteria of decisive importance for the determination of a soil are the present dynamic, chemical, physical, morphological and biological characteristics of its profile. Therefore, where these criteria show the presence on the site of an original forest soil of a peat soil or a steppe soil, for instance, the soil in question has ceased to be a forest soil, because its whole dynamics have taken a different direction.

Stage V. : Sub-Types of Common Forest Soils of Temperate Zones.

We know very many varieties of forest soils, and they have been grouped in many different ways. It is my conviction that the sub-division of a main type must be effected on the same basis as the main type itself—meaning in this case that *we must take as our basis the various degrees or intensities of the dynamic system of forest soils.*

We have seen that the most characteristic criteria for determining forest-soil profiles are the podsol and the accumulation horizons. We can distinguish three degrees in the development of the podsol horizon—viz.: (*a*) a well-developed whitish-grey or white horizon, the *true podsol horizon* (A_2). In this case the A horizon consists of A_0, A_1, and A_2, the first (A_0) being the humus cover of the soil, the second (A_1) being the upper part of the eluviation horizon more or less coloured by infiltration of humus from the surface cover, and the third (A_2) being almost white—*the true podsol horizon*—and *sharply distinguished* from the rusty-brown or blackish-brown B horizon lying below it. (*b*) In the second degree *there is no distinctly developed podsol horizon, the whole A_1 and A_2 sub-horizons being united in a single horizon lighter in colour* than the B horizon below it. This degree corresponds roughly to what GLINKA calls a "slightly podsolic horizon." What GLINKA calls *podsolic horizon**—the intermediate degree—character-ised by the A_2 horizon not being homogeneously developed, contain-ing only a few white spots or veins, is *not definite enough* to be used as a basis for the subdivision of the main type. This must therefore be included in the first degree, the difference being described as a difference of development. (*c*) In the third degree of podsolisation *the eluviation horizon cannot be detected with the naked eye—i.e.*, there is no visible boundary between the A and B horizons. In such cases

* See GLINKA, K.: "Typen d. Bodenbildung," p. 69.

podsolisation is evidenced *only by a partial leaching down from the upper horizon of the sesquioxides and their accumulation in the B horizon*.

Consequently, we may distinguish three sub-types of forest soils which differ only in respect of the A horizon.

But in the illuviation horizon we also find considerable variations, observable mostly in the case of true podsols. In its general character the B horizon is a horizon coloured brown by iron oxide, more or less irregularly cracked, and rich in colloids. In some cases the illuviation horizon shows the presence of an easily visible humus precipitation below the A_2 horizon which makes the upper part of the B horizon (B_1) darker in colour than the lower parts. Another peculiarity of the illuviation horizon—a peculiarity which develops most typically in the case of loose sandy soils—is the occurrence of iron concretions, boulders or iron hard pans. Since all these formations originated from the coagulation and precipitation of the colloidal dispersions removed from the upper eluviation horizon, they are found where the migration from the A horizon of the mobile colloidal dispersions is considerable—*i.e.*, in true podsols. These formations are to the best of my knowledge not present in slightly podsolic or apparently non-podsolic forest soils. Consequently this three-grade differentiation of the illuviation horizons is for the moment applicable only to true podsols.

We may therefore divide the main type of forest soils into the following sub-types:

Sub-Type 1.—The soil profile shows a true podsol horizon (A_2), with a simple rusty-brown B horizon.

Sub-Type 2.—The A horizon is similar to that in the preceding sub-type, but in the B horizon we find iron ore.

Sub-Type 3.—The A horizon is similar to that of Sub-Type 1; but the upper part of the B horizon (B_1) is darkly coloured by humus. No iron ore.

Sub-Type 4.—The same as Sub-Type 3, only containing iron ore.

Sub-Type 5.—Has a quite definite greyish (podsolic) horizon (A), which is *readily distinguishable* from the accumulation horizon (B) below it, though often only by its lighter colour and compacter structure.

Sub-Type 6.—It is difficult to differentiate the A and B horizons in the soil profile; *only chemical analysis will enable us to decide* whether there is an A and a B horizon. Such are, for instance, the so-called *brown forest soils* and many so-called *brown earths* in the profiles of which *we cannot detect any visible difference between the A and B horizons*.

Stage VI. : Local Varieties.

Perhaps in no other soil type are there so many and so different local varieties as in the forest soils. This is due in the first place to the fact that the main dynamic process itself may, as a consequence of the complex interaction between the several soil-forming factors,

produce profiles of varying character; while further variations may be introduced by local conditions.   Such local conditions are:

(1) *Orographical Conditions.*—The local type varies considerably, particularly in the case of occurrences in mountainous regions, according to whether the soils occur on steep or gentle slopes, on the tops of mountains or in valleys.   On slopes erosion may always assert its influence, although closed forests and the undergrowth and humus cover of forests afford the soil effective protection against erosion and wind action.   This can be seen by observing the profile of a soil skirting a road cut into a hillside; even in the case of grey forest soils there are great variations in the depth of the rusty-brown B horizon.

(2) *Hydrographical Conditions.*—We have seen already that the forest soils systematically occupy a position between the more humid meadow soils on the one hand and the drier "brown earths" or black steppe soils on the other. Thus, where, for instance, the ground-water table rises near to the surface, the forest soil approaches nearer to the more humid type; while where the subsoil is dry it approaches the drier types.

(3) *Local Climatic Conditions.*—The climate exercises a profound influence on the development of the forest vegetation.   It is comprehensible, therefore, that in the case of local varieties the situation (whether the forest faces south or north), the usual direction of the rainfall, winds, etc., all affect the vegetation and thereby the soil itself.

(4) *Local Geological Conditions.*—According to some authorities, the reason why FALLOU chose as basis of his scientific classification of soils the geological or petrographical origin was that the quality of the brown forest soils or brown earths depends upon the local geological conditions.*   Although true podsol soils may be formed from all kinds of parent rocks—as, indeed, forest soils may be formed both from calcareous and non-calcareous rocks—nevertheless the quality of the parent rock determines the quality of the forest and still more the formation and quality of the local type.   (See the section on "Brown Earths," Subsoil Order 13.)

(5) The development of the sub-types is measured by the changes in colour, thickness, structure, etc., of the different horizons.   This can be illustrated best by giving on a reduced scale the average thickness of each horizon of the profile, adding in brackets the maximum and minimum values.

Main Type 4: Truncated Forest Soils.

The reason why we have included this type is that forest soils are often formed on hillsides which are so steep that erosion washes away the upper horizons of the profile, the result being that the B horizon

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* See FALLOU, F. A.: "Die Hauptbodenarten der Nord- und Ostseeländer des deutschen Reiches, naturwissenschaftlich wie landwirtschaftlich betrachtet," Dresden, 1875.

becomes the upper (surface) layer, without there being any change, however, in the original dynamics of the soil.

The truncated forest soils retain the character of true forest soils. On them, also, a temporary humus cover is formed, with an accumulation (eluviation) horizon below it; but both are periodically washed away by erosion, leaving only traces of the original horizons. On the general soil map of Europe STREMME designates these podsolic soils as follows: " Podzolige Waldböden, stark zersetzt, Bleichhorizonte selten " (podsolic forest soils, highly decomposed, podsol horizon rarely found), and states in an explanatory note: " Es findet sich in Deutschland (rheinisches Schiefergebirge) in Polen (polnische Mittelgebirge), in Norwegen (im Süden und an der atlantischen Küste). Nach dem Klima hätte man starke Bleicherdebildung zu erwarten, dieses kommt aber infolge der grossen Geländeneigung nicht zur Ausbildung, dagegen werden die B Horizonte mehr oder weniger mächtig."* This definition corresponds practically to what I have already said about the formation and characterisation of truncated forest soils. That I have not included them in one of the sub-types of common forest soils, but have made a separate main type of them, is due to the fact that these truncated forest soils possess a peculiar dynamics of their own and are therefore themselves divisible into sub-types. Adequate descriptions of truncated forest soils are, however, lacking.

Main Type 5 : Degraded Calcium Soils.

Degraded soils are generally soils of secondary formation; degradation is thus a kind of soil metamorphosis. In the degradation of calcium soils the process consists in the calcium soils changing into hydrogen soils. As such they belong, therefore, to Soil Order 10, differing from the hydrogen soils so far treated in *their profiles showing, not only the positive characteristics of degradation, but also certain residual characteristics of the former calcium soils.* The term degradation itself was first applied to steppe forest soils in 1888 by KOSTUICHEV and KORZHINSKII, although according to GLINKA† degraded tshernosems were first mentioned and described by RUPPRECHT in 1866. In this main type may be also included—following GLINKA's later definition—secondary podsolic soils which can be shown to be tshernosems in an advanced stage of degradation.‡ More recently, however, not only the transformation into hydrogen soils of tshernosems, but also that of rendzinas, has been defined as degradation.§

The term degradation implies a decrease in value, which actually occurs when a calcium soil changes into a hydrogen soil, both from the

* See STREMME, H.: " Erläuterung d. Bodenkarte," p. 17.
† For details, see GLINKA, K.: " Typen der Bodenbildung," p. 86.
‡ See STREMME, H.: " Die sekundär podsolierten grauen Waldböden d. Waldsteppe " (BLANCK's " Handb. d. Bodenlehre," Vol. III., p. 134).
§ See BLANCK's " Handb. d. Bodenlehre," Vol. III., p. 518.

agricultural point of view and as a result of the destruction of the saturated humus zeolite complex. This destruction is caused by a permanent change in the dynamic system of the calcium soil, thus producing a new main type. The transformation is gradual, lasting until the calcium soil has lost all its original characteristics and the whole profile has been converted into a typical forest or wet meadow soil. But as long as it is possible to detect traces of the original calcium-soil character, the soil is a degraded calcium soil.

STEBUTT described the process of alkalisation also as a kind of degradation, using the term " alkaline degradation " to distinguish it from other kinds. But since alkalisation is simply one form of sodium-soil formation, this phenomenon will be discussed under Soil Order 12, below.

Genetic Characteristics.—Russian scholars long ago discovered that on the northern boundary of the tshernosem zone, where the latter adjoins the southern boundary of the forest zone, forests are continually encroaching on the steppes. The transition is gradual and leads to the development of what is called a steppe-forest zone, in which the steppe vegetation is gradually being ousted by forest vegetation. FLOROV rightly described this zone as the battlefield of the two plan associations.* Similar battlefields have been found elsewhere. Degradation means a victory of forest over steppe. In his monograph on Russian tshernosems† KOSSOVICH gives a very interesting description of how in former times the Russian tshernosem zone stretched much further north and how by the constantly increasing humidity of the climate and the expansion of the forest vegetation encouraged by these conditions the forests gradually encroached more and more on the steppes. Very instructive are the arguments and proofs adduced by KOSSOVICH for the purpose of showing that the greater virility of the forest in comparison with the steppe vegetation has resulted in some of the prehistoric steppes being covered with forests. FLOROV summarised the effect exercised by forests on tshernosems as follows:‡

(1) As a result of the forest vegetation the upper horizon becomes constantly and uniformly more humid than it was when covered by steppe vegetation. (2) The forest litter provides the soil with a loose humus cover; but the soil contains less dead organic matter than under grass vegetation, which dies out every year and produces an intimate and homogeneous mixture of humus and the mineral soil particles. (3) When the organic matter decomposes, the humus formed in the forest soil is acid and mobile, whereas the humus formed in a steppe soil is neutral and stable.

Thus, when a forest encroaches on a steppe, the soil begins to alter

* See FLOROV, N.: Annal. Inst. Geologie al Romaniei, Vol. XL. (1925), p. 69.
† See KOSSOVICH, P.: " Die Schwarzerde " (1912), p. 28.
‡ See FLOROV, N.: *op. cit.*, p. 75.

in keeping with the dynamic system of the forest soil. If we traverse a primeval region untouched by man, and starting from the steppe zone pass towards the forest zone and penetrate farther and farther into the forest, we may follow practically step by step the advance of degradation as shown in the soil profile. This might be called a development of podsolisation, for ultimately we find a true podsol. But since in this case the process of transformation gradually destroys the results of an earlier constructive process, we are justified in calling it degradation.

Dynamic Characteristics.—The dynamics of degradation consist simply in the acid leaching of a soil saturated with calcium. The tshernosem extract—and, indeed, that of all calcium soils — is neutral or slightly alkaline; and the chemical changes of the whole soil are dominated by Ca cations. In an acid medium the dominant cation is hydrogen, which gradually expels the calcium from its original position. This applies not only to tshernosems but to all base-saturated soil types, but since the process of degradation has been investigated chiefly by studying the degradation of tshernosems, most of our examples are taken from these soils. The degradation of rendzinas, for instance, is similar in many respects.

FIG. 18.

In the work referred to above FLOROV* simply identifies degradation and podsolisation. STEBUTT, on the other hand, shows that there is a difference in principle between the two;† defining degradation to be a process whereby the zeolite complex saturated with bases gradually takes up hydrogen from a slightly acid medium completely deficient in bases. GEDROIZ also distinguishes between degradation and podsolisation,‡ though only in the intensity of the process, while he does not attribute to the acid humus such a destructive effect as STEBUTT does. Though the latter admits that degradation later passes into destruction—*i.e.*, podsolisation—he notes that the Russian scientists regard as degradation only that stage of podsolisation which leads to

* See FLOROV, N.: *op. cit.*, p. 77.
† See STEBUTT: "Lehr. d. allg. Bodenk.," pp. 297-8, 303-4, 357-9, 389, and 404-10.
‡ See GEDROIZ, K. K.: "Der absorbierende Bodenkomplex" (1929), pp. 92-3.

the gradual browning of the black horizon, while the moment the grey colour appears—*i.e.*, when the process of podsolisation has developed—the soil is called a podsol.

In my opinion we must distinguish from a pedological point of view between podsolic soils which still bear traces of the original calcium soil characteristics and those soils which were originally formed by the dynamics of podsolisation. In my soil system, therefore, all those hydrogen soils which were originally calcium soils and were later transformed into hydrogen soils are included in the present main type (degraded calcium soils) differences in the degree of transformation being dealt with in the different subdivisions. The dynamics of degraded soils therefore comprise not only the primitive degradation as defined by STEBUTT, but also the further processes of degradation described by FLOROV, in which not only water and carbon dioxide but also acid humus exercises a destructive influence.

It is a pity that soil science literature does not contain any figures of hydrochloric extracts of degraded soils. As regards the absorbing complex we have some information about the T complex of the profile of a degraded steppe soil from Hajdudorog in Hungary (Fig. 18).

The analysis of the soil profile—the results of which are given in Table LIV.—was made by Dr. L. KOTZMANN.

TABLE LIV

Depth of Horizons in Cm.	S Value in mg. Equiv.	Absorbed H in mg. Equiv.	T Value in mg. Equiv.	V Value $=\frac{S}{T}100.$	Percentage of Cation Equivalents, calculated to the Total T = 100.				
					Ca	Mg	K	Na	H
0-30	18·59	5·98	24·57	75·66	62·21	10·66	1·75	2·04	24·34
30-60	22·63	6·16	28·79	78·60	65·30	9·66	1·35	2·29	21·40
60-90	20·82	3·40	24·22	85·96	70·68	11·15	1·36	2·77	14·04
90-120	17·75	2·18	19·13	89·06	87·23	14·35	1·61	4·87	10·94
120-150	11·99	2·00	13·99	85·70	22·87	35·74	2·00	25·09	14·30

It will be seen that the upper horizon has already taken up hydrogen, though Ca cations still predominate. The beginning of degradation is shown by the leaching down of the carbonates and by the pH value and acidity figures.

Table LV. shows that the carbonates have been driven down to a depth of 90-120 cm. by the degradation, the upper horizons (0-30 and 30-60 cm. respectively) being already decidedly acid.

Table LVI. contains the figures for the water extracts.

So far very little has been done in the way of a chemical examination of degraded soils; for, being regarded as transitional soils, they have

TABLE LV

Depth of Horizons. in Cm.	CaCO$_3$ %	MgCO$_3$ %	pH Value in—			Hydrolytic Acidity with Ca-Acetate.
			Total CO$_2$ %	H$_2$O	KCl	
0-30	—	—	—	7·02	6·07	15·00
30-60	—	—	—	7·02	5·90	13·38
60-90	—	—	—	7·47	6·28	7·10
90-120	4·41	0·12	2·01	8·65	7·82	1·42
120-150	10·63	0·51	4·96	9·05	8·30	0·40

TABLE LVI

Depth of Horizons in Cm.	Percentage of Cation Equiv., calculated to Total Cations = 100.				Total Cation Equiv. in mg.	Percentage of Anion Equiv., calculated to Total Cations = 100.			Percentage Deficit on Anion Equiv.
	Ca	Mg	K	Na		HCO$_3$	Cl	SO$_4$	
0-30	44·23	13·46	12·50	29·81	1·04	73·08	—	3·83	23·08
30-60	50·38	17·56	6·87	25·19	1·31	73·28	—	12·97	13·75
60-90	58·68	10·78	5·99	24·55	1·67	59·28	4·79	20·36	15·57
90-120	49·70	12·12	6·67	31·51	1·65	49·70	10·91	40·61	—
120-150	21·47	19·21	4·52	54·80	1·77	40·68	18·08	42·37	—

been neglected. Recently, however, we have been finding more and more degraded soils—not only degraded tshernosems, but also degraded rendzinas.* Indeed, from a degraded soil found near Hildesheim SELKE has shown that degradation may be caused not only by forest vegetation, but also by an increase of humidity.

Physical Characteristics.—In view of the very common occurrence of calcium soils, it is probable that many degraded calcium soils have been examined from a physical point of view, though the data have not yet been collected or elaborated, and consequently we are not yet able fully to define the physical characteristics of degraded soils. What we can do is to draw general conclusions respecting the changes ensuing during the process of degradation—*e.g.*, that the favourable crumb structure of soils becomes gradually more dense and forms into coarse clods, a fact reflected very strikingly in FLOROV's photographs of the aggregates of tshernosems and degraded tshernosems.

* See BLANCK's "Handb. d. Bodenlehre," Vol. III., p. 518.

Morphological Characteristics.—The morphological characteristics of degraded soils are described most exhaustively in the work by FLOROV already referred to.   Since the development of a soil type is involved, the morphological characteristics become more and more pronounced as degradation advances.   The first morphological change in evidence is in the colouring of the soil profile.   In the case of tshernosems, for instance, we usually find that the black or dark-brown humus horizon reaches very far down and then gradually blends with the subsoil.   The first sign of degradation is when, as a consequence of the accumulation of silica particles in the upper horizon, the black colour turns grey, and the lower part of the humus horizon brown. The latter process is due partly to efflorescence of iron hydroxide and partly to the decomposition of humus.   Before the brown layer is formed from the humus horizon the $CaCO_3$ is leached out and re-precipitated, forming a sharp white line effervescing with acid.   The mycelium-like precipitate of $CaCO_3$ in the black horizon of tshernosems gradually disappears and is reprecipitated in the form of powder and microcrystals.

The original crumbly soil structure is also gradually transformed, the result being that in the upper eluviation horizon we get a horizontal plate-like or horizontal small prismatic structure in place of the original finely granular structure.   So long as the surface of the crumbs is porous (spongy) and crumbling, the surfaces of the laminar and prismatic small clods are smooth.   The brown horizon, originally consisting of coarser crumbs or granules, assumes sharply defined boundary surfaces and creates the impression of regular, upright prisms.   As we proceed downwards the size of these prisms increases, but if we hammer to pieces a large prism it breaks up into smaller prisms with smooth surfaces and not into crumbs with undulating surfaces, as do the coarser crumbs of tshernosems.   From the coarse crumbs is formed first a so-called "nutty structure," which differs from the coarse granular structure in that, although it does not form regular pencil-shaped prisms, the surfaces of the irregular nut-shaped cuboid clods are no longer spongy (porous) but smooth like nut-shells.   When these clods are crushed, they usually split up into small prisms.   Sometimes the lower surface of the soil prism is much larger than the upper surface, so that it resembles a pyramid.   The structure is then called pyramidal.

FLOROV has endeavoured to illustrate these differences in structure by photographs, but only trained experts are able to discern the differences, for their description is still defective and imperfect. Trained soil surveyors, however, are able, with the help of the morphological characteristics, to differentiate several stages of tshernosem degradation.

Biological Characteristics.—These range somewhere between the tshernosem or Ca soil and the podsolic soils respectively.   The nearer the approach of the degraded soil to the true podsols, the greater the

resemblance between its biological characteristics and those of podsol soils. The mere fact that the vegetation causing the degradation usually differs completely from the original vegetation involves a definite change in the soil biology (*e.g.*, where a steppe soil is converted into a forest soil). In the first place the rodents which eat the roots of the grasses and prefer a dry soil disappear. The only remains of these animals found today are their burrows and holes washed out from above and filled with soil. Gradually the soil ceases to be a fit habitat even for earthworms, which consequently die out too. At present, owing to a lack of positive data, we are not in a position to offer any opinion as to what changes take place in the microflora and microfauna. A certain amount of information is supplied by the fact ascertained by FLOROV that, whereas original tshernosems did not respond to nitrate fertilisers, the progress of degradation increased the effect of nitrates. This phenomenon may be explained as the result of a decrease of humus and a weakening of nitrification. There can be no doubt, however, that during the process of degradation humus decomposition and the microflora responsible for it show ever-increasing activity.

Stage V. : Sub-Types of Degraded Calcium Soils.

Most soil scientists group degraded soils according to degree of degradation, and differ only in the number and characterisation of the subdivisions they distinguish. FLOROV, who has most exhaustively studied degradation, has divided the degraded tshernosems into five grades; but most scientists know only three grades, so that it will be expedient to take these three grades as the basis for the division of the sub-types.

Sub-Type 1 : Slightly Degraded Soils.

The original crumb structure has changed to some extent to a laminar structure, the dark colour of the humus horizon having turned somewhat grey, there being also evident a " mealy " efflorescence of silica, though the transitions are still distinguishable and there is no visible browning. The carbonate horizon usually lies fairly deep. There has been a sensible increase of the hydrolytic acidity (above 8-10). Crotovines are present everywhere.

Sub Type 2 : Dark-Grey or Brown Degraded Soils (Slightly Podsolic).

Their chief peculiarity is the development of a brown illuviation horizon, which begins in the lower part of the black horizon and spreads upwards. Its lower boundary is sharply demarcated by carbonate concretions. The soil has lost its original crumb structure, while its acidity is increased and penetrates deeper. Crotovines are found here too.

Sub-Type 3: *Grey or Light-Grey Degraded Soils* (*possessing Definite Podsolic Horizons*).

These soils have another horizon (the podsolic horizon) characteristic of podsolisation; its structure is laminar and it is ash-grey in colour, with an eluviation layer often quite white in its lower part and differing entirely from the brown illuviation horizon below it. In this stage of degradation we can distinguish five very distinct horizons: (*a*) the upper grey or light-grey humus horizon (A_1); (*b*) the whitish podsolic horizon (A_2); (*c*) the brown illuviation horizon (B); (*d*) the horizon of white carbonate concretions (C_1); (*e*) the original loess (C_2). In the upper horizons the degree of unsaturation and the acidity approach the values of true podsol soils. The only remains of the steppe soils are crotovines.

Strictly speaking, the above subdivisions apply only to degraded tshernosems transformed as a consequence of forest encroachment. Steppe soils undergoing other forms of degradation, as well as degraded rendzinas, must be treated as supplementary sub-types—*e.g.*:

Sub-Type 4 : *Steppe Soils degraded by an Excess of Ground Water.*

STREMME* describes a profile of this type from the neighbourhood of Bavenstedt near Hildesheim.

Horizon A_1.—Blackish-brown, loess-like loam, 40 cm. thick, consisting partly of crumbly and partly of polygonal clods, though on the whole schistose in structure and without iron concretions.

Horizon A_2.—Dark brown, loess-like loam, 80 cm. thick; structure partly polygonal but predominantly schistose; sporadic iron concretions and slightly porous.

Transitional horizon, with numerous crotovines.

Horizon B.—Pale yellow, reddish loess-like loam, with patches of humus; very calcareous, with iron-rust stains pointing to a high water table; moderately porous.

Horizon C not determined.

Sub-Type 5 : *Degraded Rendzinas.*

STREMME describes several profiles of degraded soils formed on limestone which show the peculiarities of one-time rendzinas (*e.g.*, sharp humus boundary above limestone horizon), though both the grey colour of the upper horizon and the brownish rusty horizon (B) indicate degradation of a calcium soil.† A characteristic feature would seem to be that below the brownish B horizon there may be found some remains of the original black humus layer, which STREMME calls A_3, and which is in marked contrast to the limestone subsoil. Chemical analysis of one of these profiles shows that the accumulation

* See STREMME, H.: " Degradierte Böden " (BLANCK's " Handb. d. Bodenlehre," Vol. III., pp. 511-12).

† See STREMME: *op. cit.*, pp. 518-21.

of SiO_2 in the upper horizon and of Al_2O_3 and Fe_2O_3 in horizon B is the same as in podsolic soils.

Stage VI. : Local Varieties.

These are not yet sufficiently well known to enable us to give a general characterisation; but it is probable that here too the local orographical, hydrographical, climatic and geological conditions influence the local character of the sub-types.

Soil Order 11 : Calcium Soils
(Main Type 1 : Tshernosems or Black [Dark-Brown] Steppe Soils).

Genetic Characteristics.—Black steppe soils are formed where there is a degree of humidity and a level of temperature sufficient to promote mineral weathering and humus formation, but without excessive soil leaching or the complete decomposition of organic matter. In these soils the alkali salts are leached out of the upper horizon; $CaCO_3$ is also more or less washed down into the lower horizons, though in the humus zeolite complex there is present sufficient exchangeable calcium to ensure stability and to prevent the migration both of hydrogen and sodium ions. The original Russian term " tshernosem " for these soils has now gained international recognition; the terms " black earth " and " black soil " are not always used in a strictly identical sense.

The Russian tshernosems are formed in climates the semi-aridity of which is associated with hot summers and cold winters; they are found in decidedly continental, temperate climates. As determined by JENNY, the rain factors (LANG's system) of the European and North American tshernosem zones are as follows:

In Europe	..	..	..	..	40-70.
In the United States	..	..	..	..	41-152.

MEYER's N-S-Q values are:

In Europe	..	..	..	..	125-350.
In the United States	..	..	..	..	142-323.

Orographically, tshernosem formation requires a slightly undulating territory or a plain—under no circumstances a closed basin in which the ground water will (even temporarily) accumulate.

The parent rock may vary considerably, but is nevertheless most frequently loess or some other earth of a similarly fine structure; it is only exceptionally sand.

The original vegetation of tshernosems is grassy steppe, one of the leading constituents of which is provided by *Stipaceæ*, this being the origin of the term " steppe."

This grassy steppe vegetation does not, however, consist solely of *Stipaceæ*. In Russia there are two distinct plant associations of the kind. The first is the *Stipa*-steppe vegetation proper, the dominant plants of which are *Stipa capillata* (common feather grass), *Stipa pennata, Stipa Lessingiana, Festuca sulcata*. In frequent association with these are: *Koeleria cristata, Triticum cristatum, Poa bulbosa* var. *vivipara, Carex stenophylla, Medicago falcata, Tulipa Gesneriana, Iris pumila*, etc.

The other plant association—the *meadow steppe*—is far more variegated, as besides Graminaceæ large numbers of dicotyledons occur. The plants of the *Stipa* steppes occur too, though not to so considerable an extent as above, and the following additional plant species are associated with them: *Adonis vernalis, Adonis volgensia, Salvia nutans, Salvia austriaca, Astragalus pubiflorus, Astragalus asper, Onobrydies austriacus, Gypsophila paniculata, Centaurea marschaliana, Centaurea trivernia, Phlomis tuberosa, Aster amellus, Cambre tatarica, Statice latifolia, Pæonia tenuifolia, Phleum Baehmeri, Triticum ramosum*, etc. In moist depressions the following Graminaceæ are dominant: *Poa pratensis, Triticum repens, Hierochloa odorata*, mixed with the following dicotyledons: *Libanotis montana, Trifolium pratense, Inula salicina, Filipendula Ulmaria*.

The typical fauna of steppes are earthworms and rodents living in the earth; we often find the underground burrows (crotovines) of the latter containing their skeletons. These latter do not live in forest soils, being found at most on the fringes of forests. They are, indeed, serious obstacles to the formation of a forest, for they attack the young trees and their roots. The earthworms, which are also often found in well aerated forest soils, play a prominent rôle in the development of the crumbly structure of tshernosems.*

The microbiological properties of tshernosems are little known at present, but from the general behaviour of these soils and from their chemical and physical composition we can conclude that the most important processes prevailing in these soils are oxidation and aerobic decomposition, which produce the mild humus so characteristic of tshernosems—though their formation is certainly also conditioned by their whole dynamic system being dominated by calcium cations.

Dynamic Characteristics.—The circumstances governing the formation of tshernosems are such that the bases released during the weathering of silicates are only slightly leached out. The easily soluble alkali salts are leached out of the upper horizon—frequently, indeed, out of the lower horizons too; but the less easily soluble salts of Ca and Mg ($CaCO_3$, $MgCO_3$ and $CaSO_4$) are only partly leached. Thus the decomposition of silicates is practically dominated by Ca cations, the first result being Ca zeolites—*i.e.*, an absorbing complex saturated with calcium. Whether we imagine the process as taking place through

* See KOSSOVICH, P.: " Die Schwarzerde (Tschernoziom)," Verl. f. Fachliteratur, G.M.B.H., Berlin (1912), p. 48.

the complete silicate decomposition and subsequent zeolite formation described by STEBUTT, or conceive it as resulting from the partial and gradual hydrolysis and decomposition of the original silicates—in both cases alike *the result is a complex saturated principally with calcium*. STEBUTT calls these soils *zeolite-forming*. No calcium zeolites can be formed or remain, however, *unless there is a predominance of calcium cations in the soil solution too*.

As regards the dynamic equilibrium of the soil, the essential thing is that *steppe vegetation only develops where it finds sufficient mineral nutrients to satisfy its high mineral requirements*. The grass roots bring minerals up from the lower layers, the result being that the dead vegetable matter on the surface actually increases the base content of the soil.

This is why tshernosem soils—even when they are excessively humiferous—are never acid and are always rich in plant food. STEBUTT, indeed, says that *in the natural state tshernosems become richer and richer*, because the steppe vegetation concentrates in the upper horizons the stock of plant food of the lower horizons. To this is largely due the saturation of the humus-zeolite complex, principally with Ca, though partly also with Mg.

As a consequence of the latter fact the colloidal complex is also coagulated. The humus, therefore, does not migrate, the deep humus layer being formed *in situ* from the dead vegetation. Another point worth mention is that the deposition of the falling dust still continues to add to the thickness of the upper layer. The fauna living in the soil provides for the mixing of the materials contained in the different horizons.

The dynamic characterisation of tshernosems would be incomplete without a negative feature, which is a logical consequence of what has been said. *The sesquioxides*—Fe_2O_3 *and* Al_2O_3—*are immobile*, while in the hydrogen and sodium soils respectively they are mobile. The moment the predominance of the Ca cations ceases, either owing to an increase in the number of H ions (as in the case of degraded tshernosems) or as a consequence of the infiltration of Na ions (as in the case of alkali tshernosems), both the sesquioxides and the humus migrate, the result being the formation of the well-known eluviation (A) and illuviation (B) horizons, which are entirely lacking in tshernosems. *In the tshernosems their place is taken in the lower layers usually by a calcium (on rare occasions by a gypsum) accumulation horizon.*

Chemical Characteristics.—The consequences of the dynamic conditions described above are also evident in the chemical composition. The oldest chemical investigations showed that the composition of the mineral material remains practically unchanged throughout the whole profile. *This phenomenon has often been erroneously interpreted as meaning that in tshernosems there is no leaching*, but as KOSSOVICH showed, the slight leaching of bases is counterpoised by their transport into the upper horizon by the rich vegetation. Thus, leaching, particularly of the water-soluble sodium salts, occurs in tshernosems

also, *but it is characteristic for the leaching medium that it is dominated by calcium cations, the result being that the reaction is practically neutral or only slightly alkaline*, for the soil contains a considerable amount of $CaCO_3$, the alkalinity of which in pure water corresponds to $pH = 8 \cdot 0 \text{-} 8 \cdot 3$.

In the work by KOSSOVICH already referred to there is a large number of soil analyses which enable us to summarise the chief characteristics of tshernosems as follows.*

One of the characteristic properties of tshernosems is the remarkably high humus content, which in the case of the Russian tshernosems most frequently amounts to 6-10 per cent. in the upper horizon (roughly 20 cm. in depth). Among more than 1,000 profiles examined there were, however, also soils with a humus content of less than 4 per cent., there being others with 20 per cent. or more. A point of special interest with regard to the origin of this soil type is that the soils richest in humus are found on the central line of the tshernosem zone, while those poorer in humus occur on the borders.

The reason for this phenomenon is that on the boundary between the tshernosem zone and the northern humid zone the tshernosems are degraded, the humus becoming mobile as a consequence of the leaching of calcium. In the southern boundary zone, on the other hand, the drier climate causes a scarcity of humus-forming vegetation. This fact at the same time affords striking evidence of the importance of climate in the formation of tshernosems.

The humus of tshernosems is saturated and stable; consequently it hardly disperses or dissolves at all. The Russian scientists have always taken this circumstance into account and have determined the ratio of the water-soluble to the total organic matter. The proportion of water-soluble organic matter in Russian tshernosems is $0 \cdot 02 \text{-} 0 \cdot 05$ per cent., representing $0 \cdot 5 \text{-} 0 \cdot 7$ per cent. of the total organic matter. The organic matter itself is absolutely homogeneous, without any trace of the original plant structure. It may be regarded as *completely humified, making these soils a striking contrast to the turf soils, which are also rich in organic matter.* The humus content usually decreases with depth in the profile, the decrease being generally gradual and only occasionally rapid. The richness in organic matter is accompanied by a high nitrogen content—usually from $0 \cdot 2$ to $0 \cdot 5$ per cent., representing barely 5 per cent. of the total organic matter.

Although the mineral part of tshernosems varies considerably, the composition—apart from the carbonates and the humus—is practically the same throughout the profile. This is illustrated by GLINKA's data relating to an East Siberian tshernosem profile:†

* It should be noted that since the appearance of KOSSOVICH's work many chemical problems which were then unsolved have been cleared up, particularly as a result of GEDROIZ's researches. Due account has been taken of the new data in the present work.

† See GLINKA, K.: "Typen der Bodenbildung," p. 128.

TABLE LVII

Horizons.			A₁	A₂	C
Loss on ignition	..	..	11·04	6·38	4·63
SiO₂	..	..	58·32	61·28	62·50
Al₂O₃	..	..	15·87	18·00	17·70
Fe₂O₃	..	..	6·09	5·62	6·50
CaO	..	..	3·42	2·80	2·91
MgO	..	..	2·05	2·29	2·21
K₂O	..	..	2·20	2·15	2·44
Na₂O	..	..	1·37	1·59	1·50
Total	..		100·36	100·11	100·29

If we calculate the results shown in Table LVII. to material free of organic matter, we get the following figures:

TABLE LVIII

Horizons.			A₁	A₂	C
SiO₂	..	..	65·55	65·45	65·53
Al₂O₃	..	..	17·84 ⎱ 24·68	19·22 ⎱ 25·22	18·56 ⎱ 25.37
Fe₂O₃	..	..	6·84 ⎰	6·00 ⎰	6·81 ⎰
CaO	..	..	3·84	2·99	3·05
MgO	..	..	2·30	2·44	2·31
K₂O	..	..	2·47	2·29	2·45
Na₂O	..	..	1·54	1·69	1·57

These figures show that the mineral composition of the whole profile is practically the same. This is not always strictly so, but, as we shall see later on, the hydrochloric extract gives similar results.

Our knowledge of the chemical characteristics of the Russian tshernosems has been supplemented in an instructive manner by the results of recent investigations of Hungarian black steppe soils.* Table LIX. shows the fusion analysis of a black steppe soil from Mezőhegyes calculated to soil dried at 105° C. and to soil free of humus and carbonates respectively.

Only the $CaCO_3$ and the $MgCO_3$ have been leached out into the lower horizons to any considerable extent, together with smaller quantities of Na_2O, while the organic matter ($C \times 1·72$) has accumulated in the upper horizons. This is confirmed by the hydrochloric extract analysis as shown in Table LX.

* See SIGMOND, A. A. J. VON, and KOTZMANN, L.: "Steppenschwartzerde auf Lössuntergrund" (Math. u. Naturwissentschaftlicher Anzeiger d. ung. Akademie d. Wissenschaften), Band LIII. (1935), p. 91.

TABLE LIX

Fusion Analysis, calculated to Soil dried at 105°, in %.

Depth in Cm.	0-30	30-60	60-90	90-120	120-150
Na₂O	1·28	1·12	1·44	1·38	1·43
K₂O	2·50	2·30	2·54	2·26	2·18
MgO	2·21	2·29	2·41	3·28	3·69
CaO	4·79	8·59	9·36	9·40	10·02
MnO	0·19	0·20	0·18	0·19	0·29
Fe₂O₃	5·03	4·85	4·75	5·60	5·27
Al₂O₃	12·88	12·11	11·82	11·01	10·97
SO₃	0·10	0·1	0·13	0·16	0·17
P₂O₅	0·19	0·17	0·14	0·14	0·12
CO₂	2·67	6·24	7·13	7·20	8·09
SiO₂	60·62	55·59	55·24	54·96	54·52
TiO₂	0·30	0·42	0·19	0·26	0·29
Loss on ignition	7·79	5·40	4·93	4·62	3·67
Total	100·55	99·39	100·26	100·46	100·71
C×1.72	3·67	2·15	1·22	0·84	0·58
CaCO₃	5·31	12·90	14·43	14·40	15·63
MgCO₃	0·61	1·07	1·49	1·65	2·32
CaCO₃+MgCO₃	0·88	0·91	0·89	0·89	0·85

Percentage, calculated to Humus- and Carbonate-Free Soil=100.

Depth in Cm.	0-30	30-60	60-90	90-120	120-150
Na₂O	1·41	1·34	1·74	1·66	1·75
K₂O	2·76	2·74	3·06	2·72	2·67
MgO	2·17	2·15	2·04	2·99	3·17
CaO	1·99	1·63	1·54	1·61	1·56
MnO	0·21	0·24	0·22	0·23	0·35
Fe₂O₃	5·56	5·79	5·73	6·73	6·46
Al₂O₃	14·24	14·45	14·26	13·24	13·44
SO₃	0·11	0·13	0·16	0·19	0·21
P₂O₅	0·21	0·20	0·17	0·17	0·15
SiO₂	67·00	66·35	66·63	66·07	66·81
TiO₂	0·33	0·50	0·23	0·31	0·35
Loss on ignition	4·56	3·87	4·48	4·45	3·79
Total	100·55	99·39	100·26	100·46	100·71

TABLE LX

Analysis of the HCl Extract, calculated to Soil dried at 105° C., in %.

Depth in Cm.	0-30	30-60	60-90	90-120	120-150
Na_2O	0·27	0·34	0·58	0·48	0·55
K_2O	0·58	0·54	0·51	0·51	0·42
MgO	1·65	1·98	1·73	2·66	3·10
CaO	4·51	8·06	9·22	9·12	9·71
MnO	0·08	0·08	0·12	0·17	0·27
Fe_2O_3	3·77	3·35	3·35	4·25	4·02
Al_2O_3	5·47	5·11	3·69	4·01	3·94
SO_3	0·10	0·11	0·13	0·16	0·17
P_2O_5	0·19	0·17	0·14	0·14	0·12
CO_2	2·67	6·24	7·13	7·20	8·09
SiO_2	10·79	9·66	9·75	9·50	8·98
TiO_2	0·19	0·21	0·17	0·18	0·14
Insol. residue	61·98	58·60	58·27	57·24	57·08
Loss on ignition	7·79	5·40	4·93	4·62	3·67
Total	100·04	99·85	99·72	100·24	100·26

Percentage, Calculated to Humus- and Carbonate-Free Soil=100.

Depth in Cm.	0-30	30-60	60-90	90-120	120-150
Na_2O	0·30	0·40	0·70	0·58	0·67
K_2O	0·64	0·64	0·62	0·61	0·51
MgO	1·50	1·76	1·23	2·25	2·44
CaO	1·68	1·00	1·38	1·27	1·18
MnO	0·09	0·09	0·14	0·20	0·33
Fe_2O_3	4·17	3·99	4·04	5·11	4·93
Al_2O_3	6·05	6·07	4·46	4·82	4·83
SO_3	0·11	0·13	0·16	0·19	0·21
P_2O_5	0·21	0·20	0·17	0·17	0·15
—					
SiO_2	11·94	11·53	11·77	11·42	11·01
TiO_2	0·21	0·25	0·20	0·22	0·17
Insol. residue	68·58	69·89	70·37	68·85	70·04
Loss on ignition	4·56	3·88	4·48	4·55	3·79
Total	100·04	99·85	99·72	100·24	100·26

TABLE LXI

Soil.	Depth of Horizon (Cm.).	S Value in mg. Equiv.	U Value Degree of Unsaturation (mg. Equiv.)	T_p Value in mg. Equiv.	Percentage of Exchangeable Cations, calculated to $T_p=100$.					V_p Value $=\dfrac{S\,100}{T_p}$
					Ca	Mg	K	Na	H	
Mezőhegyes ..	0–30	21·55	0·4	21·95	85·06	10·88	0·77	1·46	1·82	98·18
	30–60	15·90	0·3	16·20	74·69	18·83	1·60	3·02	1·85	98·15
	60–90	15·58	0·1	15·68	49·23	44·71	2·04	3·38	0·64	99·36
	90–120	16·67	—	16·67	23·51	66·05	2·46	7·98	—	100·00
	120–150	9·01	—	9·01	21·64	59·60	4·77	13·98	—	100·00
Gyula	0–30	17·80	0·2	18·00	80·78	10·05	7·39	0·67	1·11	98·89
	30–60	16·56	0·2	16·76	79·71	11·22	4·71	3·22	1·19	98·81
	60–90	14·24	0·2	14·44	58·93	22·85	9·90	6·92	1·38	98·62
	90–120	13·46	—	13·46	11·14	55·65	26·67	9·14	—	100·00
	120–150	9·50	—	9·50	—	59·79	27·16	13·05	—	100·00
Békéscsaba ..	0–30	14·04	0·3	14·34	77·61	12·41	4·32	3·56	2·09	97·91
	30–60	12·44	0·2	12·64	71·67	16·06	5·22	5·46	1·58	98·42
	60–90	11·30	—	11·30	66·19	16·64	9·11	8·05	—	100·00
	90–120	9·76	—	9·76	37·81	25·00	26·13	11·07	—	100·00
	120–150	8·21	—	8·21	6·33	43·36	37·03	13·28	—	100·00

TABLE LXII

In 100 Grammes Soil Dried at 105° C.

Soil.	Depth of Horizon (Cm.).	Dry Matter (mg.).	Ignited residue (mg.).	CO₃ (mg.).	HCO₃ (mg.).	Cl (mg.).	SO₄ (mg.).	CaO (mg.).	MgO (mg.).	K₂O (mg.).	Na₂O (mg.).
Mezőhegyes ..	0-30	121·6	60·8	—	76·3	4·5	5·4	25·8	3·0	13·8	10·2
	30-60	124·8	64·6	—	59·8	6·7	7·8	28·6	3·5	9·1	34·2
	60-90	214·4	118·4	—	60·1	18·9	23·2	32·5	9·1	6·7	53·2
	90-120	400·0	253·8	—	88·7	21·3	102·0	31·3	17·9	4·4	87·4
	120-150	431·2	262·3	—	43·4	36·8	125·6	28·4	15·2	7·4	95·6
Gyula ..	0-30	—	—	—	64·0	2·9	3·4	25·3	5·2	18·5	11·6
	30-60	—	—	—	61·0	8·4	6·9	21·6	5·2	12·3	16·5
	60-90	—	—	—	61·0	6·7	14·5	23·9	3·9	21·2	15·3
	90-120	—	—	20·6	195·2	11·3	14·3	10·5	7·5	51·1	50·4
	120-150	—	—	59·2	148·8	9·2	8·7	7·1	10·1	73·0	83·7
Békéscsaba ..	0-30	121·6	75·2	—	54·3	—	5·1	19·9	2·6	21·2	3·4
	30-60	164·0	52·0	—	53·7	2·8	5·6	24·1	2·3	11·5	6·7
	60-90	121·6	70·16	—	58·6	16·7	10·8	19·2	3·6	15·4	12·4
	90-120	124·8	100·8	—	87·7	13·5	9·9	17·6	8·5	30·0	11·6
	120-150	219·2	194·2	—	129·5	12·9	11·5	15·3	10·7	40·4	27·5

TABLE LXIII

Soil	Depth of Horizon (Cm.)	mg. Equivalent in 100 Grammes Dry Soil					Percentage of Cation Equivalents, calculated to Total 100.			
		CaO	MgO	K_2O	Na_2O	Total.	Ca	Mg	K	Na
Mezőhegyes	0-30	0·92	0·15	0·30	0·33	1·70	54·12	8·82	17·65	19·41
	30-60	1·02	0·17	0·19	1·10	2·48	41·13	6·85	7·66	44·36
	60-90	1·16	0·45	0·14	1·72	3·47	33·43	12·97	4·03	49·57
	90-120	1·12	0·89	0·10	2·82	4·93	22·72	18·05	2·03	57·20
	120-150	1·01	0·75	0·16	3·08	5·00	20·20	15·00	3·20	61·60
Gyula	0-30	0·90	0·26	0·39	0·37	1·92	46·87	13·54	20·32	19·27
	30-60	0·77	0·26	0·26	0·53	1·82	42·32	14·28	14·28	29·12
	60-90	0·85	0·19	0·45	0·49	1·98	42·92	9·60	22·73	24·75
	90-120	0·38	0·37	1·08	1·63	3·46	10·98	10·69	31·22	47·11
	120-150	0·25	0·50	1·55	2·70	5·00	5·00	10·00	31·00	54·00
Békéscsaba	0-30	0·71	0·13	0·45	0·11	1·40	50·71	9·29	32·14	7·86
	30-60	0·86	0·11	0·24	0·22	1·43	60·15	7·69	16·78	15·38
	60-90	0·69	0·18	0·33	0·40	1·60	43·13	11·25	20·62	25·00
	90-120	0·63	0·42	0·64	0·37	2·06	30·58	20·39	31·07	17·96
	120-150	0·55	0·53	0·86	0·89	2·83	19·43	18·73	30·39	31·45

The essential point here is that the figures relating to Fe_2O_3, Al_2O_3 and soluble SiO_2 remain practically unchanged throughout the profile, whereas in the case of forest soils and alkali soils, for instance, the above constituents migrate downwards and accumulate in horizon B.

Table LXI. gives the data of the saturation conditions of the absorption complexes of three Hungarian black steppe soils.

These soils are 98-100 per cent. saturated, the Ca being the dominating cation in the upper horizon.

Table LXII. shows the composition of the water extract of the same three Hungarian tshernosems.

In the upper horizons the dominant anions are the carbonates, whereas in the lower horizons there are also considerable quantities of sulphates and chlorides. This undoubtedly shows that the mobile alkali salts are probably not completely leached out from the lower horizons. In the central and northern zones of Russia the accumulation horizon of the alkali soils probably lies much deeper than in the Hungarian lowlands, which are drier than the central and northern zones of the Russian tshernosems. Hence exchangeable sodium accumulates in the lower horizons, as has occurred in the case of the above-mentioned black steppe soils.

Of special interest are the relative quantities of water-soluble cations. Though the data of Table LXII. show that the dominant cation in the upper horizon is calcium and that Na, K and Mg cations increase with the depth at the cost of Ca, these facts are seen far better from the data of Table LXIII., which shows the mg. equivalents of the water-soluble cations and the ratio of the same to the total cation equivalents.

Table LXIV. shows the reaction conditions and carbonate contents of the soils.

Physical Characteristics.—Practically the only permanent physical characteristics about which we possess pedological data are those referring to the mechanical composition. It is, however, difficult to compare the results of the various methods used. In the work already referred to, KOSSOVICH gives two tables showing comparable data, from which it may be seen that the mechanical composition of tshernosems varies considerably, a fact to be attributed to the varying character of the parent rock. However, as in the case of the chemical composition, there are no important differences in the mechanical composition of the horizons of any one profile.

Table LXV. gives the mechanical composition of the profiles of the Hungarian black steppe soils referred to above.

We find all sorts and conditions of tshernosems—from sand to heavy clays.

Nevertheless, both the Russian and the Hungarian tshernosems (black steppe soils) belong for the most part to the category of clay soils possessing a medium or low degree of plasticity—probably the result of the absorbing complex being saturated with calcium.

TABLE LXIV

Soil.	Depth of Horizon in Cm.	pH in—		CaCO$_3$ %	MgCO$_3$ %	Total CO$_2$ %
		H$_2$O	KCl			
Mezöhegyes ..	0-30	8·41	7·70	5·31	0·61	2·67
	30-60	8·48	7·79	12·90	1·07	6·24
	60-90	8·44	7·89	14·43	1·49	7·13
	90-120	8·49	8·12	14·40	1·65	7·20
	120-150	8·41	7·99	15·63	2·32	8·09
Gyula	0-30	8·88	8·34	1·69	0·10	0·80
	30-60	9·00	8·48	5·25	0·28	2·46
	60-90	9·00	8·56	7·95	0·44	3·74
	90-120	9·15	8·75	10·08	0·97	4·95
	120-150	9·24	8·72	13·12	1·56	6·62
Békéscsaba ..	0-30	8·89	8·15	2·70	0·11	1·25
	30-60	8·79	8·31	7·58	0·25	3·47
	60-90	8·75	8·48	13·82	0·26	6·22
	90-120	8·79	8·21	12·02	0·48	5·53
	120-150	9·05	8·41	10·56	0·53	4·97

TABLE LXV

Soil.	Depth of Horizon (Cm.).	Coarse Sand (2·0-0·2 Mm.).	Fine Sand (0·2-0·02 Mm.).	Silt (0·02-0·002 Mm.).	Clay (<0·002 Mm.).
Mezöhegyes	0-30	2·9	47·8	25·9	23·4
	30-60	3·1	48·2	26·1	22·6
	60-90	2·0	46·9	30·3	20·8
	90-120	3·3	45·8	29·9	21·0
	120-150	2·9	47·1	29·7	20·3
Gyula	0-30	1·8	55·4	27·9	14·9
	30-60	1·2	54·3	29·9	14·6
	60-90	2·0	51·9	30·8	15·3
	90-120	2·5	52·4	29·0	16·1
	120-150	2·2	52·5	30·4	14·9
Békéscsaba	0-30	2·8	56·8	26·2	14·2
	30-60	1·9	55·7	29·5	12·9
	60-90	1·6	56·4	28·3	13·7
	90-120	1·6	55·3	30·5	12·6
	120-150	0·9	56·1	28·9	14·1

Morphological Characteristics.—In the profiles of tshernosems we can distinguish really only two horizons—the upper, humiferous A horizon and the parent rock or C horizon. Some scientists call the transition horizon the B horizon. In my opinion this may cause confusion, because the B horizon usually refers to an horizon of accumulation. It will be better, therefore, to accept STREMME's designations; STREMME denotes the various varieties of tshernosem profiles as follows:*

A	ACa			
C	ACa	ACa	A	A
	CCa	CCa	CCa	ACCa
	CCa	CCa	CCa	C

In these types of profiles A represents the humiferous horizon, C the parent rock, while the Ca added to the C and the A respectively means that in the horizon in question we find $CaCO_3$.

In its natural state the A horizon is crumbly in structure. This property the soil owes alike to the absorbing complex being saturated with calcium and to the peculiar fauna and flora of tshernosems. The flora is very rich in roots and penetrates deep, interweaving with the layers of soil. The fauna—in particular earthworms—grub up the upper horizon, swallowing both the dead organic and the mineral matter, which they later excrete in the form of small clods. This process of cracking and trituration is furthered also by periodical intense drying, when the soil cracks along deep-lying roots. All these natural factors cause the structure of the tshernosem to become crumbly in the upper horizons (where it is composed of tiny clods), and there is an increase in the size of the clods at depths where no earthworms penetrate and where roots are fewer. Here, too, however, the tshernosem finds its cultivators in the rodents. These burrow the soil through and through to make their underground dwellings accessible, though their work is seen principally in certain multicoloured patches. In the upper humiferous horizons we find light patches; while in the light lower horizons black patches mark the original nests and passages or runs since filled in by the subsoil or by soil from the upper layers. We very often find skeletons of small animals preserved in the buried tunnels, and very characteristic white veins resembling fungus mycelia on the surfaces of the small soil clods; these veins, called *pseudo-mycelia,* are calcareous precipitations ($CaCO_3$ and $CaSO_4$). As the water solution passes along the surfaces of the cracked clods, it becomes concentrated, the calcium salts dissolved from the upper horizon precipitating on the surface. In the bigger cracks or where a thick root lies, larger calcareous concretions, which the Russians call *bieloglazka* or white eye-spots, are formed.

Another characteristic feature of the tshernosem profile is that it

* See STREMME, H.: "Böden der feuchttrockenen gemässigten Regionen" (BLANCK's "Handbuch," Vol. III., 1930, p. 259).

is usually perpendicularly cracked—like loess—and does not show any horizontally layered structure. Generally the upper humiferous horizon only gradually merges into the subsoil, the only exceptions being where the subsoil is hard rock (mountain tshernosems).

As regards the distribution of calcium carbonate, the upper horizon is usually leached, so that it either does not effervesce at all or much less than the lower horizons. Where the parent rock itself is lime-free, it may happen that beyond a certain depth there is no effervescence at all. In the latter case we find a definite lime-concretion horizon, though where the parent rock is rich in lime the lime-accumulation horizon is not always found.

Below the $CaCO_3$ horizon we often find a gypseous horizon too, showing that gypsum, being more easily soluble in water, precipitates after calcium carbonate during the leaching process.

It is this leaching down of the $CaCO_3$ that causes the soil profile to become more and more alkaline with the increase of depth.

The parent material of steppe soils becomes loose during the formation of a tshernosem. This is probably the result of intensive action on the part of the soil-forming factors. Very frequently, however, the parent material itself is loose—e.g., loess. In such cases we cannot see any marked difference between the original parent material and the C horizon lying just below the humiferous horizon. The profile of a black steppe soil of this kind is illustrated in Plate IV, Profile 7.

Not infrequently we find a darker—so-called " humus "—horizon in the subsoil of tshernosems. This is usually a *buried* or *fossil* soil, probably the residue of a tshernosem originating in one of the more humid periods of loess formation which, when the climate became drier, was once more covered with loess, its scanty vegetation dying and decaying.

A fact worth mentioning is that along the roots the humiferous horizon in places projects tongue-like into the light subsoil, producing a very irregular, as well as gradual, transition from one horizon to the other.

As the tshernosems are humiferous soils formed in dry climates, the water table is usually so low (about 9-10 metres below the surface) that we cannot find it in normal profiles. Consequently the water régime depends upon the precipitation and evaporation conditions, the ground water playing a very insignificant rôle.

In the upper horizons of cultivated tshernosems the original crumbly structure naturally disappears, both because the fauna perishes and the soil loosened by cultivation is more or less puddled and compacted by rain. This process is naturally not so intensive as in the case of soil types with unstable colloids. Tshernosems are, however, easily cultivated and very friable.

Biological Characteristics.—Tshernosems in the natural state possess a flora and fauna of a peculiar character which have already been

described, and which are naturally closely connected with the soil microflora. As is generally known, grass vegetation needs not only abundant mineral plant food, but also a considerable quantity of nitrate nitrogen. The porous structure of tshernosems, their neutral or slightly alkaline reaction, their calcium-soil character and their temperate humidity and temperature conditions, all favour the activity of the bacteria which decompose humus and which induce nitrification. An increase in the humus content under natural conditions merely shows that the humus formation is more active than its decomposition.

The fact that there is no raw-humus cover on the surface of tshernosems—as forest soils—itself proves that the original dead organic matter decomposes rapidly. The decomposition is not complete, however, and there remains—besides gaseous substances—a black or dark-brown structureless material.

Soils under cultivation lose the original permanent soil-enriching grass vegetation. Under such circumstances the fauna living in the soil also perish or migrate. Although the mechanical work of the fauna can be more or less replaced by the aid of soil-cultivating implements, the harvesting of the crops causes a decided loss of plant food, while the periodical bareness of the soil may also lead to further losses.

Practical experience proves that these soils are most suitable for grain cultivation. We do not thereby suggest that they are unsuitable for the cultivation of more pretentious plants, such as sugar beet, which, however, needs a more humid climate and is of poor quality when grown on a tshernosem. All the disadvantages can, however, be eliminated by adequate irrigation, which also produces excellent results in the case of permanent meadow vegetation and fodder plants. In other words, *tshernosems are suitable for all types of cultivation* if we employ irrigation or suitable methods of cultivation (*e.g.*, " dry farming ") to ensure the activity of the only uncertain factor of agrarian production and to make good the deficiency in moisture. Tshernosems are excellent *wheat soils*, even without irrigation, and are typical *lucerne soils*. Usually the chief requirement is for phosphoric acid, less frequently for nitrogen and most rarely for potash.

Stage V. : Sub-Types of Tshernosems.

We can distinguish three degrees of leaching in soils derived from both calcareous and non-calcareous parent rocks. In the case of non-calcareous parent rocks the characteristics of the three degrees are as follows:

(1) With excessive leaching, the whole profile is carbonate-free, and there is no accumulation of sodium salts in the lower horizons. The humus content is not high; in Russia it varies from 4-10 per cent. (northern zone), and may be less. The humus horizon (A) is

not very deep—about 40-60 cm. thick, or even less. The profile symbol is:

$$\frac{A}{C}$$

(2) With medium leaching, the lower part (A_2) of the A horizon is enriched with $CaCO_3$ formed during the process of weathering. There are no sodium salts even in the lower horizons. This is the common tshernosem in Russia. Its humus content varies from 6-10 per cent., the depth of the humus horizon being 60-80 cm. The profile symbol is:

$$\frac{A_1}{A_2Ca}{C}$$

(3) The degree of slight leaching differs from the foregoing ones in that in the C horizon sodium salts occur either in the lower part (C_2) only or in both upper part (C_1) and lower parts. Thus this degree includes theoretically two sub-types with the following symbols:

(1) $\dfrac{A_1}{A_2Ca}{C_1}{C_2Na}$ (2) $\dfrac{A_1}{A_2Ca}{C_1Na}{C_2Na}$ or $\dfrac{A_1}{A_2Ca}{CNa}$

We have no definite data at present about the typical humus content or depth of humus horizon characteristic of the different types.

In the case of calcareous parent material, the three degrees are as follows:

(1) With high leaching, the upper horizon (A) may be either completely or partly carbonate-free (the presence of 0·1-0·2 per cent. $CaCO_3$ is neglible). The essential point is that the amount of $CaCO_3$ increases constantly with the depth, while the lowest horizon remains free of sodium salts. The profile symbols are:

$$\frac{A_1}{A_2Ca}{CCa}$$ $$\frac{A_1}{A_2}{CCa}$$ or $$\frac{A}{CCa}$$

(2) With medium leaching, the A horizons all contain carbonates, and the carbonate content increases perceptibly with the depth. In the C_2 horizon there are some sodium salts. Probably many of the southern tshernosems belong to this sub-type; they contain a moderate humus content (4-6 per cent.) and are of moderate depth (40-60 cm.). The profile symbol is:

$$\frac{ACa}{C_1Ca}{C_2CaNa}$$

(3) With slight leaching, the sodium salts rise up to the beginning of the A horizon. The soils belonging to this degree form a transition to the dry steppe soils. Their symbol is:

$$\frac{ACa}{CCaNa}.$$

In time it may become necessary to distinguish even more sub-types, and we shall be able to make the zonal Russian types fit in with these dynamic subdivisions. For the moment, however, we have to content ourselves with the sub-types already dealt with, which usually occur zonally or regionally as a consequence of the determining influence exercised upon the degree of leaching by the climatic factors. The sub-types known to us may be formulated as follows:

(1) $\dfrac{A}{C}$ (2) $\dfrac{\begin{array}{c}A_1\\A_2Ca\end{array}}{C}$ (3) $\dfrac{\begin{array}{c}A_1\\A_2Ca\end{array}}{\begin{array}{c}C_1\\C_2Na\end{array}}$ (4) $\dfrac{\begin{array}{c}A_1\\A_2Ca\end{array}}{CNa}$

(5) $\dfrac{\begin{array}{c}A_1\\A_2Ca\end{array}}{CCa}$ (6) $\dfrac{A}{CCa}$ (7) $\dfrac{ACa}{\begin{array}{c}C_1Ca\\C_2CaNa\end{array}}$ (8) $\dfrac{ACa}{CCaNa}.$

   (9) Tshernosems on sandy parent material.
   (10) Tshernosems on compact rocks.

There may be degrees of leaching in the case of the two latter sub-types too, but they are not yet known.

Stage VI. : Local Varieties.

Local varieties of the tshernosem sub-types are the results of environmental conditions.

(1) Local *orographical* conditions. Though tshernosems are usually found in flat territory, they may nevertheless occur in hilly regions too—being found alike on plateaus, on gentle slopes, in wet valleys or in the depressions of drier steppes.

(2) Local *hydrographical* conditions. A *sine qua non* of the formation of tshernosems is that the ground water shall not stagnate in the subsoil, but shall be drained off. In other words, the water table must lie at a great depth. Naturally, in the case of a drier climate a rise in the water-level may moisten the soil and make it suitable for tshernosem development, which otherwise would have been prevented by the drought. In more humid regions, on the contrary, what causes the development of a tshernosem is the sinking of the water-level. These soil humidity conditions may occur naturally or may be brought about by artificial means (*e.g.*, drainings or irrigation).

(3) Local *climatic* conditions. Naturally in any climatic region

local variations must determine the measure and direction of the development of the dynamics of any given profile or soil. Special importance attaches to local climatic variations in regions in which— like the Hungarian lowlands—arid and humid climates meet, and where extreme climatic changes are therefore the rule rather than the exception.

(4) *The quality of the parent material.* When discussing the subdivisions of the sub-types, we saw that certain properties of the parent material exercise a decisive effect upon the development of the subtypes. In order fully to understand the dynamics of a local sub-type, we must first consider closely the character of the parent material— *e.g.*, its mineral composition, degree of both chemical and physical weathering, geological origin, etc.

(5) Apart from the local factors mentioned above the age of development of the soil influences its formation. It should be noted that in general the development of tshernosems requires a relatively long period.

Main Type 2 : " Prairie " Soils.

The " prairie " soils of North America were long considered as identical with the Russian tshernosems.* During the excursion following the First International Soil Science Congress held at Washington in 1927, however, it was almost unanimously agreed that these soils, although originally steppe soils, only to a very slight extent presented the same characteristics as true tshernosems. Most of them must have come into existence under conditions somewhat more humid than the tshernosems, though they cannot have been quite so humid as those governing the formation of degraded tshernosems or slightly podsolic grey and brown forest soils, belonging to Sub-types 5 and 6 of my soil system. This hypothesis is supported also by the geographical distribution of the prairie soils given in MARBUT's map.† MARBUT treats the prairie soils as a separate group, on the following grounds: " The soils are so entirely different from those of any other great groups that, for the present, it seems very unwise to attempt to include them in any of the established groups. . . . The prairie soils are grassland soils, but were developed under a high rainfall. In this respect they seem to be unique, not occurring elsewhere in the world except possibly in small areas, and where they do occur have heretofore been designated as chernozems."‡

Genetic Characteristics.—According to JENNY the following figures show the fluctuations in MEYER's N-S-Q values of the humidity factors:

* See KOSSOVICH, P.: " Die Schwarzerde," pp. 140-2.
† " Atlas of American Agriculture," Part III., " Soils of the United States," by C. F. MARBUT: Plate II.
‡ *Ibid.*, p. 62.

			N-S-Q.	*Mean Annual Temperature.* (° C).
American tshernosems	..	..	140-250	3-12°
American prairie soils	..	..	260-350	—
American brown forest soils	..	..	280-400	6-16°

Here too the natural vegetation is Gramineæ, though according to STREMME the plant association of the Russian tshernosems represents the drier group of Gramineæ and that of prairie soils the more humid group. SCHANTZ divides the vegetation of prairie soils into several groups determined by climate.* In any case it is a moot point whether these extensive prairies have always been prairies, as the climatic conditions are quite suitable for forest vegetation.† It has long been a mystery why, while forests in Russia, for instance, have already annexed huge territorities from the original steppes, there has not been a similar expansion of forest land in America. Some scholars attribute the inability of the forests to expand to destruction by fires, and others to the depredations of the original prairie fauna. According to STREMME the difference between prairie soils and genuine tshernosems is that the high water table of the former encourages the development of wet-meadow vegetation. FLOROV's investigations show that in the subsoil of the northern prairie soils we find rusty veins indicating an over-abundance of moisture.‡ FLOROV§ therefore groups these northern prairie soils with the wet-meadow soils, and the southern prairie soils with the degraded tshernosems. Should FLOROV's deductions prove correct—he admits that he had not sufficient time to make a thorough investigation of all the phenomena— the present main type will be superfluous, for the northern prairie soils would then belong to the degraded calcium soils. MARBUT, however, points out that there is a difference between prairie soils and degraded tshernosems. The latter contain in their deeper layers a $CaCO_3$ horizon, whereas the prairie soils—despite the less intense surface eluviation—do not show any $CaCO_3$ horizon in the subsoil.||

Dynamic Characteristics.—The data are inadequate, and all we can say is that owing to the higher soil humidity eluviation is more intensive than in the tshernosems, so that the H ions begin partly to usurp the rôle of the Ca ions.

Chemical Characteristics.—In illustration of the chemical characteristics of prairie soils JENNY gives ROST's analyses,¶ which show the

* "Atlas of American Agriculture," Part I., "Natural Vegetation." *Cf.* SCHANTZ, H. L.: "Grassland and Desert Shrub" (Washington, 1924), pp. 15-19; STREMME, H.: "Die Prairieböden" (Blanck's "Handbuch," Vol. III., p. 281).

† See GLEASON, H. A.: Annals of the Ass. Amer. Geogr., Vol. XII. (1922), pp. 39-85.

‡ FLOROV, N.: Soil Research, Vol. I. (1929), p. 208.

§ *Ibid.*, p. 201.

|| See MARBUT, C. F.: Soil Science, Vol. XXV. (1928), pp. 61-70.

¶ See ROST, C. O.: "Parallelism of the Soils developed on the Gray Drifts of Minnesota" (1918).

composition of the profile of a prairie soil from the village Rice in Minnesota. STREMME uses the same data for the characterisation of prairie soils, calculating the figures to a carbonate-free soil less the loss on ignition.* These figures are given in Table LXVI.:

TABLE LXVI

Depth of Horizon in Cm.	Percentage of the Constituents in Dry Soil.				Percentage calculated to Carbonate- and Humus-Free Soil.			
	2·5-15	18-30	33-61	63-91	2·5-15	18-30	33-61	63-91
SiO_2	72·89	73·62	75·24	73·65	80·42	79·86	79·68	77·80
Al_2O_3	10·46	10·87	11·35	12·13	11·52	11·79	12·01	12·81
Fe_2O_3	2·99	3·21	3·42	3·81	3·30	3·48	3·62	4·02
MgO	0·72	0·74	0·88	1·21	0·80	0·80	0·93	1·28
CaO	1·24	1·18	1·24	2·08	1·25	1·21	1·13	0·77
Na_2O	1·39	1·35	1·33	1·31	1·53	1·46	1·41	1·38
K_2O	1·66	1·74	1·86	1·87	1·83	1·89	1·97	1·97
TiO_2	0·50	0·52	0·54	0·53	0·55	0·57	0·57	0·56
P_2O_5	0·18	0·17	0·14	0·11	0·20	0·18	0·15	0·12
CO_2	0·07	0·05	0·13	1·06	—	—	—	—
Loss on ignition	9·38	7·80	5·34	2·99	—	—	—	—
Total	101·48	101·25	101·47	100·75	101·40	101·24	101·47	100·71

It will be seen from the above figures that as we proceed downwards there is a gradual decrease in the amounts of SiO_2, CaO, Na_2O and P_2O_5, accompanied by a corresponding increase in the amounts of Al_2O, Fe_2O_3, MgO, K_2O and CO_2. According to the data given by TRUOG, the soil is slightly or moderately acid.

For another prairie soil (Marshall silty loam) BRADFIELD† has obtained the following values in addition to the pH:

Depth of horizon	0-45 cm.	45-75 cm.	75-120 cm.	120-150 cm.	
Total exchangeable bases	16·6	16·9	17·5	26·0	mg. equiv.
Exchangeable hydrogen	6·54	7·81	8·29	6·48	
Absorption capacity	23·1	24·7	25·8	32·5	
pH value	6·31	5·67	5·55	6·33	
N	0·176 %	0·135 %	0·078 %	0·044 %	
Sand	0·3 %	0·2 %	0·6 %	0·5 %	
Silt	74 %	70 %	67 %	69 %	
Clay	24 %	30 %	32 %	30 %	

* See BLANCK's "Handbuch der Bodenlehre," Vol. III., p. 293.
† See BRADFIELD, R.: "Variations in Chemical and Mechanical Composition in Some Typical Missouri Profiles" (Am. Soil Survey Ass. Bull., VI., 1925, pp. 127-45).

These soils are therefore slightly unsaturated. The clay content increases with the depth.

The data given by BYERS and ANDERSON show that the prairie soils in some respects resemble the true American tshernosems. Ratios compiled from the data of the total analysis of the soil colloids are given in Table LXVII., which has been drafted on the basis of the original figures.*

These data are interesting and characteristic, because they are based upon the total chemical analysis of the colloidal fraction (diameter 0·3 μ or less) of the soils.† If we compare the data relating to the two prairie soils with those relating to the two calcium soils, we find on the whole that practically all the figures belong to one and the same order of values, showing that the differences are of a very minor character. This seems to show that the chemical composition of prairie soils is almost the same as that of true calcium soils, for which reason we may—for the present at least—include them in the calcium soil order. It is, however, equally certain that they form a kind of transition from calcium to hydrogen soils. I have therefore for the present included these soils as being nearly related to tshernosems in the calcium soil order.

Physical Characteristics.—Prairie soils in general belong to the category of clay or heavy loam soils, due partly to the humidity conditions favouring the chemical decomposition of minerals and partly to the formation of a sufficient amount of organic matter thoroughly mixed with the mineral part, as in the case of tshernosems. The difference in structure which distinguishes these soils somewhat from normal tshernosems is probably to be attributed to the slight unsaturation of the absorbing complex.

Morphological Characteristics.—MARBUT has given morphological descriptions of several prairie soil profiles,‡ occurring at various points in the long prairie belt and corresponding to the various plant associations described by SCHANTZ.

Biological Characteristics.—Biologically, we may divide the prairie belt running from north to south into three sub-types corresponding to the natural and cultivated plants. STREMME has characterised these three sub-types as follows:§

(1) The *Andropogon furcatus* plant association, which includes both *Andropogon scoparius* and *Sorghastrum nutans* and other flowering plants. The central part of this area is the " corn belt."

(2) The *Andropogon scoparius* plant association, in which the

* See BYERS, H. G., and ANDERSON, M. S.: Journ. Physical Chemistry, Vol. XXXVI. (1932), pp. 348-66).

† See ROBINSON, W. O., and HOLMES, R. S.: " The Chemical Composition of Soil Colloids " (U.S. Dept. Agric. Bull., 1311, 1924).

‡ See MARBUT, C. F.: " Soil Classification " (Amer. Soil Survey Ass. Bull., 3, pp. 24-32).

§ See BLANCK's " Handbuch," Vol. III., pp. 288-9.

TABLE LXVII

Name and Type of Soil.	Depth of Horizon in Inches.	SiO₂ + Al₂O₃ + Fe₂O₃ = 100.			Molecular Ratios of—				mg. Equiv. of the Mono- and Bivalent Bases in 100 Grammes Colloidal Clay.					Total of the Exchangeable Base Equivalents in 100 Grammes Colloids.
		SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	$\dfrac{SiO_2}{Al_2O_3 + Fe_2O_3}$	$\dfrac{SiO_2}{Al_2O_3}$	$\dfrac{SiO_2}{Fe_2O_3}$	$\dfrac{Fe_2O_3}{Al_2O_3}$	Ca	Mg	K	Na	Total.	
Marshall prairie soil	0-14	59·97	28·36	11·67	2·82	3·58	13·14	0·263	42·5	99·7	47·3	6·8	196·3	—
	14-36	60·07	27·43	12·50	2·87	3·72	12·59	0·292	48·5	80·3	44·0	4·8	177·6	—
Shelby prairie soil	0-7	58·35	29·90	11·75	2·64	3·31	12·40	0·252	47·1	92·7	25·5	7·1	172·4	—
	8-12	57·99	29·81	12·20	2·61	3·30	11·42	0·262	46·0	92·8	24·0	6·8	169·6	—
	12-20	57·83	29·80	12·36	2·60	3·28	11·18	0·265	48·9	100·2	26·8	9·3	175·9	—
	20-24	57·56	29·09	13·35	2·60	3·36	10·80	0·294	58·2	107·7	28·0	12·3	206·2	—
	24-48	58·41	27·75	13·84	2·71	3·57	13·61	0·319	77·4	102·7	34·6	14·2	228·9	—
	48-60	57·98	27·79	14·23	2·67	3·54	12·72	0·328	83·8	102·7	35·2	13·2	234·9	—
Amarillo (Tex.) tshernosem	0-5	62·09	27·09	10·82	3·10	3·88	15·19	0·255	52·8	103·2	56·9	1·9	220·8	56·6
	10-20	62·19	27·42	10·39	3·09	3·85	15·84	0·243	56·7	132·0	53·9	0·3	242·9	62·8
	30-40	62·43	27·28	10·29	3·13	3·87	16·06	0·241	65·4	138·9	53·1	1·9	259·3	63·4
	54-64	61·35	28·84	9·81	2·97	3·60	16·57	0·217	61·7	140·4	51·4	3·2	256·7	69·2
	70-75	62·20	28·56	9·24	3·06	3·68	17·79	0·207	75·0	125·5	38·9	1·9	241·3	65·6
	96-100	62·97	27·57	9·46	3·18	3·86	17·66	0·219	56·4	142·4	48·0	0·3	247·1	70·0
Barnes (S. Dak.), tshernosem	0-2·5	62·65	23·47	13·88	3·30	4·53	11·93	0·379	59·2	47·6	44·8	58·1	209·7	—
	14-48	60·89	23·85	15·26	3·09	4·32	10·57	0·408	46·7	63·0	41·0	45·5	196·2	—
	60-78	64·00	21·48	14·52	3·55	5·05	10·31	0·432	—	—	—	—	—	—

Andropogon furcatus has been relegated to a subordinate position, while the drier climate usually encourages short-stemmed grasses. This area comprises *the American winter-wheat soils*, and is confined to the southern and western parts of the belt.

(3) The *Stipa spartea* and *Agropyron tenerum* plant association, which is found in the northern section of the prairie belt; this area comprises the *spring-wheat belt*. It is slightly drier than area 1, but also much colder.

Main Type 3 : Rendzinas.*

The origin of these calcium soils is due primarily to the active calcium of the parent rock. GLINKA calls the rendzinas " endo-dynamomorphic," a term meaning that their character is determined principally by internal forces—*e.g.*, by the parent rock.† He suggests that in cases where the action of external soil-forming factors—*e.g.*, climate—should produce podsolisation, the limestone parent rock obstructs the process and produces a humus accumulation similar to that in evidence in tshernosems.

Genetic Characteristics.—A parent rock rich in calcium carbonate or gypsum, which neutralises the podsolising effect of the humid climate, is essential for rendzina formation. But rendzinas do not form on all calcareous parent rocks in humid climates; for the effect exercised by the calcareous parent rock depends not only upon its $CaCO_3$ content, but also upon the fineness of its structure and its solubility. According to MIKLASHEWSKI‡ there is a whole series of rendzinas varying according to the character of the parent rock.

GLINKA, and most of the Russian pedologists, regard rendzinas as transitional formations leading in time to podsolisation—the latter process ensuing where the $CaCO_3$ has been sufficiently leached out.§ MIKLASHEWSKI, on the other hand, declares that this never happens in the case of true rendzinas.|| STEBUTT explains the formation of rendzinas as due to the active Ca ions which oppose the predominant destructive factors and cause the formation of stable zeolites and humus, for which reason he calls them intrazonal tshernosem forma-

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* According to MIKLASHEWSKI the agrarian people of Poland call " rendzinas " the soils formed from calcareous or gypseous parent rocks. The meaning of the word is doubtful, though it certainly has not the meaning attributed to it by GLINKA. The term " rendzina," according to MIKLASHEWSKI, may be derived from the Polish verb " rzedzic " (to tremble), owing to the sound heard when it is being cultivated. Where the limestone is visible with the naked eye, the Poles call the soil *shrahp* (snorer), as it emits a " snoring " sound when it is being cultivated. The soils in the Department of Lublin formed on chalk are called " borovinas," though these too are rendzinas.

† See GLINKA, K.: " Typen d. Bodenbildung," p. 213.

‡ See MIKLASHEWSKI, SLOW.: Compte Rend. de la II. Conf. Intern. Agro-pédologique à Prague, 1922, pp. 312-7.

§ See GLINKA, K.: " Typen d. Bodenbildung," pp. 35 and 217.

|| See MIKLASHEWSKI: *op. cit.*, p. 314.

tions.*   There are certainly cases in which rendzinas may be podsolised or degraded, but that is true of tshernosems too; yet the latter have never been described as transitional formations. Genetically, the difference between the two main types is that whereas in the case of tshernosems all the external factors favour the development of black steppe soils, in the case of rendzinas the external factors are practically all antagonistic to the internal (the parent rock), the character of the soil eventually formed depending upon the ultimate balance between the two opposing actions.

Rendzinas are formed by the action of a humid climate under the influence of forest vegetation; but the result is never a typical forest soil. The peculiarity of the type lies in the fact that, although in their natural state they are covered with forest vegetation, they are not true hydrogen soils, but belong to the order of calcium soils, resembling in their external appearance tshernosems more than forest soils. Rendzinas are of very frequent occurrence, and are not confined to the northern humid and cold climate. Recently DEL VILLAR discovered in the drier districts of Spain soils resembling rendzinas, the chemical composition of which shows that they are calcium soils.†

Dynamic Characteristics.—The absorbing complex is almost entirely saturated, the Ca cations predominating also in the soil solutions. While on the one hand

FIG. 19.—PROFILE OF A TYPICAL RENDZINA SOIL AT BUDAÖRS (HUNGARY).

the abundance of moisture furthers the decomposition of the humus and the minerals, on the other hand, owing to the fact that the Ca ions derived from the $CaCO_3$ bind the humic acids and impede their continued decomposition, there is an accumulation of neutral humus. The SiO_2 and the Al_2O_3 released by the decomposition of the silicates are also precipitated by the Ca cations, which retain them in the upper horizon in the form of stable zeolite-like complexes. In this respect, therefore, *the dynamics of rendzinas resemble those of*

* See STEBUTT, A.: " Lehrb. d. allg. Bodenkunde," pp. 387-9.
† See DEL VILLAR, E. H.: " Les sols méditerr. étudiés en Espagne " (1930, Madrid), pp. 208-12.

TABLE LXVIII

Percentage of Constituents, calculated to Soils dried at 105° C.

Name of Soil.	Ördögorom.			Sopron.		Bélapatfálva.		Percentage in Humus- and Carbonate-Free Soils.		
Horizon and Depth.	A 0-26 Cm.	C₁ 26-100 Cm.	C₂ Below 100 Cm.	A 0-20 Cm.	C Below 20 Cm.	A 0-30 Cm.	C Below 30 Cm.	Ördögorom. A	Sopron. A	Bélapat-fálva. A
Na₂O	0·21	—	—	0·37	—	0·16	—	0·26	1·76	0·59
K₂O	0·19	—	—	0·17	—	0·24	—	0·23	0·81	0·88
MgO	2·28	18·57	20·88	0·31	0·24	0·40	0·90	1·21	1·47	1·48
CaO	3·28	26·86	30·96	41·18	54·17	36·90	54·09	2·12	4·14	4·19
MnO	0·26	—	—	0·27	—	0·18	—	0·32	1·28	0·66
Fe₂O₃	5·24	} 0·10	} 0·07	1·91	} 0·16	2·43	} 0·26	6·47	9·09	8·92
Al₂O₃	2·16			0·84		1·16		2·66	3·99	4·26
SO₃	0·14	} 0·06	} 0·05	0·23	} 0·14	1·18	} 0·09	0·17	1·09	0·66
P₂O₅	0·18			0·09		0·19		0·22	0·43	0·70
CO₂	2·42	41·40	47·01	31·68	42·54	28·10	43·11	—	—	—
SiO₂	6·28	—	—	2·79	—	3·46	—	7·75	13·29	12·71
TiO₂	0·16	—	—	0·11	—	0·20	—	0·20	0·52	0·73
Insoluble residue	59·68	12·65	0·95	12·09	1·63	16·71	0·76	73·66	57·55	61·37
Loss on ignition	17·18	0·04	—	8·04	0·54	9·63	0·08	4·39	4·66	2·79
Total	99·66	99·68	99·92	100·08	99·12	99·94	99·29	99·66	100·08	99·94

tshernosems. Consequently over the limestone there accumulates a mild-humus soil, the colour of which varies from black to grey according to the circumstances of formation. The humiferous layer is usually very distinctly marked off from the white subsoil. There are cases, however, in which we find a yellowish or reddish transition horizon (*e.g.*, in Spain). DEL VILLAR, for instance, asserts that the red earths of the Mediterranean have been formed from eroded rendzinas.*

Chemical Characteristics.—Though rendzinas are common in Poland and—according to GLINKA—in North Russia, there are very few and inadequate chemical analyses relating to these soils, and it would be a difficult matter to describe their chemical characteristics. GLINKA has given us the analyses of the hydrochloric extracts of three German rendzinas, but the results do not give a picture of the whole profile. The profile examined by COUNCLER is that of a degraded rendzina.†

Recently, with the help of my assistant DR. KOTZMANN, I analysed a few Hungarian rendzinas,‡ the composition of the hydrochloric extracts of which is given in Table LXVIII.

It will be seen that the original parent rock (C, C_1 and C_2) is mostly composed of carbonates, but owing to leaching very little of the latter has remained in the surface soil.

The figures given in Table LXIX. show the saturation conditions of the Hungarian rendzinas.

TABLE LXIX

Rendzina from—	S Value.	U_p Value.	T_p Value.	Percentage of Exchangeable Cations, calculated to $T_p = 100$.					$V_p = \dfrac{S}{T_p} 100$.
				Ca	Mg	K	Na	H	
Budaörs ..	50·06	4·80	54·86	69·27	16·37	1·93	3·68	8·75	91·25
Ördögorom ..	38·72	3·12	41·84	68·79	19·02	2·98	1·56	7·65	92·35
Sopron ..	32·98	1·84	34·82	92·21	2·38	1·15	2·10	2·16	97·84
Bélapátfalva ..	36·29	1·71	38·00	89·70	3·44	2·36	0·90	3·60	96·40

Although these data show that the saturation of the absorbing complex of rendzinas—especially of those formed on dolomites—is not so complete as in the case of tshernosems, rendzinas may nevertheless be regarded as fairly saturated Ca soils. The exchangeable Ca in the case of rendzinas formed on $CaCO_3$ is 89-92 per cent., while in the dolomitic rendzinas it is only 68-69 per cent.

* See DEL VILLAR, E. H.: *op. cit.*, p. 210.
† See GLINKA, K.: *op. cit.*, pp. 216-7.
‡ See SIGMOND, A. A. J. VON, and KOTZMANN, L.: " Die dynamische Characterisierung der ungarischen Rendzinaböden" (Math. u. Naturwiss. Anzeiger d. Ung. Akademie d. Wissensch., Vol. LIII., 1935), p. 111.

There is, however, a material difference between the negative nucleus of the absorbing complex of the above rendzinas and of tshernosems respectively. For, if we regard the *matière noire* of GRANDEAU as active humus and accept its valency as shown by KOTZMANN's* recent investigations to be 308·7 (*i.e.*, 324·2 mg. equivalent bases for every 100 gramme active humus), allotting the remaining valencies of bases to the silicate complex, we find a significant difference between the two calcium soils. The relevant figures are given in Table LXX.

TABLE LXX

Soil.	Depth of Horizon in Cm.	Active Humus (%).	mg. Equiv. of Active Humus.	T_p Mg. Equiv.	Percentage of Humus Equiv. calculated to $T_p = 100$.
Rendzinas :					
Budaörs	—	11·42	37·69	54·86	68·5
Ördögorom		8·96	29·63	41·84	70·8
Bélapátfalva		7·02	23·17	38·00	60·9
Sopron		6·18	20·39	34·82	58·5
Tshernosems :					
Mezöhegyes	0-30	2·13	7·03	21·95	32·0
	30-60	1·38	4·55	16·20	34·3
	60-90	0·88	2·90	15·68	18·5
	90-120	0·67	2·21	16·67	13·2
	120-150	0·52	1·72	9·01	19·0
Gyula	0-30	1·86	6·14	18·00	34·1
	30-60	1·13	3·72	16·76	22·2
	60-90	0·77	2·54	14·44	17·6
	90-120	0·55	1·81	13·46	13·4
	120-150	0·41	1·35	9·50	14·2
Békéscsaba	0-30	1·41	4·65	14·34	32·4
	30-60	1·10	3·63	12·64	28·7
	60-90	0·76	2·51	11·30	22·2
	90-120	0·48	1·58	9·76	16·2
	120-150	0·38	1·25	8·21	15·2

From the above figures we see that 58-70 *per cent. of the absorbing complex of rendzinas consists of active humus, whereas in the case of tshernosems less than 35 per cent. of the absorbing complex consists of humus, the bulk being composed of silicates.* There will be no difficulty in understanding this when we consider that the black upper horizon of rendzinas is formed owing to organic matter being neutralised by lime and magnesia, which impede the eluviation or decomposition of

* See KOTZMANN, L.: "A humusz szerepe az absorbciós komplexumban" (Mezögazd. Kut., Vol. II., 1929), p. 537.

the humic acids produced.   In rendzinas there is no accumulation of humus except in the surface layer, whereas in tshernosems the humus is distributed evenly to a considerable depth in the parent rock.

The proportions (per cent.) of the water-soluble cations are summarised in Table LXXI.

TABLE LXXI

Rendzina from—	Water Soluble Cations in mg. Equiv.				Total mg. Equiv. of Cations dissolved.	Percentage of Water-Soluble Cations calculated to Total m.g. Equiv. =100.			
	Ca	Mg	K	Na		Ca	Mg	K	Na
Budaörs ..	0·54	1·68	0·18	0·46	2·86	18·89	58·74	6·29	16·08
Ördögorom	0·67	1·26	0·22	0·32	2·47	27·13	51·01	8·91	12·95
Sopron ..	0·74	0·27	0·12	0·26	1·39	53·24	19·42	8·64	18·70
Bélapátfalva	0·99	0·36	0·09	0·39	1·83	54·10	19·67	4·92	21·31

Here again we see that in the water extract the dolomitic rendzinas are sharply distinguished from the calcareous ones.   In the former case the dominant constituent is Mg. and in the latter Ca.

Physical Characteristics.—The characteristic feature of the mechanical composition of rendzinas is that the upper humiferous horizon still contains much coarse débris, gravel and sand, the silty and clayey parts being small, thus again showing considerable difference from the mechanical composition of the tshernosems usually formed from loess.   The relevant data are given in Table LXXII.

TABLE LXXII

Rendzina from—	Boulders > 20 Mm.	Gravel 20-2.0 Mm.	Coarse Sand 2.0-0.2 Mm.	Fine Sand 0.2-0.02 Mm.	Silt 0.02-0.002 Mm.	Clay < 0.002 Mm.
Budaörs ..	5·7	25·9	22·5	21·6	18·5	5·8
Ördögorom ..	14·3	20·1	28·7	18·4	9·3	9·2
Sopron ..	—	—	61·4	18·4	13·3	6·9
Bélapátfalva	9·7	11·2	40·3	25·6	8·9	4·3

Morphologically, rendzinas are characterised by the humiferous surface horizon being usually sharply distinguished from the parent rock.   It would appear, however, that in a sub-tropical climate— *e.g.*, in Spain—transitional iron horizons are also found, and develop,

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according to DEL VILLAR, into the *terra rossa* of the Mediterranean. More information on this point will be found in the section dealing with red earths.

Biological Characteristics.—As forest soils, rendzinas are suitable for calcicole species of trees. As arable land, they are usually poor in plant food and often suffer from drought, as the subsoil very rapidly drains off the water and the surface soil cannot replace the water which evaporates. In places formerly covered with forests this causes the formation of " karst "—a very frequent and dangerous phenomenon.

Stage V. : Sub-Types of Rendzinas.

MIKLASHEWSKI has grouped the rendzinas of Poland according to the parent rock.* Seeing that the whole dynamics of the soil formation are determined by the original parent rock, and as we have no other basis available, we must for the moment accept this classification as our starting-point.

MIKLASHEWSKI first divides rendzinas into two groups: (A) carbonate, and (B) sulphate group. In the carbonate group he distinguishes the following sub-groups:

A. Carbonate Rendzinas.

I. *With Marly Subsoil.*

(a) Rendzinas formed from native marl, according to geological ages:

1. Rendzina or borovina (a) black, (b) white, (c) yellow	Cretaceous.
2. Granular rendzina	Tertiary.
3. Jurassic rendzina	Jurassic.

(b) Rendzinas formed not of native marl :

1. Podsolic rendzina or borovina (black, white or yellow respectively)	Diluvial-Cretaceous.
2. Slightly podsolic rendzina, etc.	
3. Loess-like mixed rendzina, etc.	
4. Podsolic Jurassic rendzina	
5. Slightly podsolic Jurassic rendzina	Diluvial.
6. Loess-like Jurassic rendzina	Jurassic.

II. *On Calcareous Parent Rock.*

1. Chalk rendzina	Cretaceous.
2. Lateritic rendzina	Jurassic.

III. *On Dolomitic Parent Rock.*

1. Dolomitic rendzina	Triassic.

B. Sulphate Rendzinas.

1. Gypseous rendzina	Tertiary.

Unfortunately, the scientific data available are insufficient to allow of my attempting to characterise in more detail the main and sub-groups. The data published are rather agricultural in character.†

* See MIKLASHEWSKI, S.: " Gleby Ziem Polskich " (" The Soils of Poland "), 2nd Ed. (1912), p. 52.

† See MIKLASHEWSKI, S.: Compte rend. Conf. Extraord. (III. Intern.) Agropédologique, Prague, 1922, pp. 312-37.

Main Type 4: Tropical and Sub-Tropical Black Earths (Black Soils).

It is impossible to distinguish a type strictly; at most there is a similarity or resemblance determined by identity of climate and by identity of external appearance and a similarity of the conditions of cultivation. In former times these soils were simply classified as tshernosems, identical with the black earths of Russia. It was the " regur " soils of India that first attracted attention owing to their having been used for agricultural production for over 2,000 years without manure and without becoming exhausted. These soils are still the principal cotton-growing areas of India. Kossovich* describes the " regur " soils as black earths which are clayey, heavy and sticky, being 1-2 (in exceptional cases 5) metres in depth, and here and there have a brownish or greyish tinge. Below these soils there is a loess-like parent material which rests on gneiss or trap. But in some districts the " regur " soil has developed directly from the weathered basaltic trap rock. The annual precipitation is 1,200 mm., or even less—a very low rainfall for a tropical climate, particularly when we take into account the fact that there are alternate wet and dry seasons. This, indeed, is the reason why leaching is confined to the $CaCO_3$, which accumulates in the lower layers in the form of concretions known locally as " kunkar " or " kankur " or " kunkur." Under natural conditions these soils are treeless and are covered with a grassy and shrubby vegetation.

Many scholars have investigated the origin and black colour of the " regur " soils.† Despite numerous contradictions, it would appear that the black colour is due principally to organic matter, as in the case of tshernosems. Nevertheless, the high clay content of these soils and the frequent formation of cracks 12-15 cm. wide and 1-2 metres deep point to their structure being different from that of the Russian tshernosems. It may be, of course, that the cracks are the result of the climate being warmer and more extreme.

Hilgard identifies the " regur " soil with the " black adobe " of California, though the latter is extremely difficult to cultivate, and has therefore very little in common with the black earths of Russia. Yet, although we are unable for the moment to define these tropical soils exactly, we may plausibly assert that they are calcium soils in which a considerable amount of mild humus accumulates.

Giesecke‡ would include in this group the "badob" of the Sudan, the " pampas " of Argentina, the " tirs " of Morocco, and indeed all the black earths occurring in the sub-tropics. Although these soils may climatologically belong to the same category—albeit relevant figures

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* See Kossovich, P.: " Die Schwarzerde," pp. 137-9.
† Cf. Blanck's " Handbuch," Vol. III., pp. 342-4.
‡ See Giesecke, F.: " Subtropische Schwarzerden " (Blanck's " Handbuch," Vol. III., p. 341).

on that point are still inadequate—in respect of soil genetics and dynamics they are probably different soil types, which have here been included provisionally in a single main type.

Main Type 5: Brown Steppe Soils.

Russian soil scientists distinguish several grades of brown steppe soils—viz., dark-brown, chestnut-brown and light-brown. It will be best to deal with the dark-brown steppe soils in connection with the black steppe soil, since in the wet state they look black, the brownish-black colour only appearing when they are dry. There are many soils of this kind among the southern Russian and the Hungarian tshernosems.

The chestnut soils are lighter in colour. Docuchaiev regarded them as a separate type following after tshernosems. Sibirtzev, however, included them in the dry steppe zone, to which the light-brown and grey, so-called " semi-desert soils " also belong. Glinka included them in a single group—that of soils formed with insufficient humidity,* the sub-groups of which are the chestnut-brown, the light-brown and the grey steppe soils. In the light-brown sub-group, however, he distinguishes those which possess a dense B horizon from those in which this compact subsoil is lacking.† The former he assigns to the solonetz soils, retaining among the light-brown steppe soils of his classification those which differ in colour only from the chestnut earths. Ramann regards the chestnut-brown soils as a sub-group of the black steppe soils, including among the latter also the light-brown soils. The grey soils, on the contrary, as being pale steppe soils, he placed in a separate group of steppe soils,‡ on the ground that they showed the lime crusts characteristic of desert soils and formed a transition between steppe soils proper and the saline soils of deserts. I myself have adopted the attitude§ that, as it is difficult to differentiate the many transitional varieties of soil on the basis of shades of colour, the thing to be stressed is the steppe character, the " chestnut-colour " or " light-brown " epithet being of only secondary importance. Consequently I have divided the soils of dry regions into three groups —viz., (a) chestnut or brown steppe soils, (b) pale or grey steppe soils, (c) saline or alkali soils. These three soil types are, in fact, found alternating on dry steppes, forming a complex soil zone.

Recently Stebutt‖ has included the light-brown and grey steppe soils among the sodium soils. But he does not give any analytical data, only noting that the zeolites of the zeolite-forming alkaline soils

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* See Glinka, K.: " Typen d. Bodenbildung," p. 132.

† See Glinka: op. cit., p. 137.

‡ See Ramann, E.: " Bodenbildung u. Bodeneinteilung," pp. 110-11.

§ See Sigmond, A. A. J. von: " Böden trockener Gebiete " (Blanck's " Handbuch," Vol. III., p. 297).

‖ See Stebutt, A.: " Lehrb. d. allg. Bodenkunde," pp. 369 and 376.

belong to the " polysorptive saloid " type. Should this determina-
tion be supported by analytical data, these brown or grey soils will
have to be grouped in our system among the sodium soils. GLINKA
also assigned the light-brown steppe soils with a compact B horizon
to the solonetz soils, though at the same time he added that there are
light-brown soils which differ from the chestnut soils in colour and
amount of humus.

It is evident, therefore, that the latter cannot be identical with
the soils which STEBUTT calls brown steppe soils. In this chaotic
question we shall not see straight until we have exact analytical data
to support the apparently conflicting theses. For the present, there-
fore, the only brown steppe soils which we can consider here are those
which differ from the chestnut earths only in being lighter in colour
and poorer in humus. Those light-brown soils which GLINKA refers
to, and which STEBUTT has included among the alkaline zeolite-
forming soils, will have to be grouped partly among the sodium soils
or included in the grey steppe soils main type. What we have said
above was necessary in order to illustrate the confusion of ideas prevail-
ing in this field and to make it clear which type of brown steppe soils
we are now dealing with.

Genetic Characteristics.—As GLINKA has shown, in these soils there
is not sufficient humidity to support so luxuriant a grass vegetation
as that found on tshernosems. The result of this is that less humus is
formed. The scantier the vegetation, the lighter the colour of the
A horizon. As a consequence, a characteristic feature of these, as
contrasted with other brown soils (brown forest soil, brown earths), is
that *their brown colour is due, not to iron hydroxide, but to organic
matter.* The soil humidity is, however, enough to prevent the accumu-
lation of alkali salts in the upper horizons.

Dynamic Characteristics.—As a consequence of the origin of the
soil type, leaching is restricted chiefly to the alkali salts, the $CaCO_3$ and
the gypsum being less intensively leached than in the case of tsher-
nosems. Another characteristic feature is that the gypseous horizon
lies deeper than the $CaCO_3$ concretions, as the gypsum is more easily
soluble than the $CaCO_3$ and the leaching is from top to bottom. Con-
versely, in all soils that suffer from excess of ground water and in
which evaporation transports the salts upwards, the gypseous horizon
is above the carbonate horizon. The sesquioxides and the soluble
SiO_2 are stable, as in the tshernosems and other calcium soils.

Chemical Characteristics.—Since in my publication referred to above*
I had recourse to chemical data of Hungarian dark-brown soils when
dealing with brown steppe soils, with which they are grouped in my
system, I shall here confine myself to a chemical characterisation of
the definitely chestnut and light-brown steppe soils.

Table LXXIII. contains the chemical composition of a typical

* See SIGMOND, A. A. J. VON: " Böden trockener Gebiete " (BLANCK's
" Handbuch," Vol. III., p. 94).

TABLE LXXIII

Constituents in the Original Air-Dry Soil.

Depth of Horizon in Cm.	CO_2 %	H_2O at 100° C. %	Loss on Ignition. %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %	K_2O %	Na_2O %	P_2O_5 %	Total %
0-5.4	—	2·89	8·25	62·78	15·01	5·09	2·45	2·14	1·72	2·18	0·150	99·992
5-12	—	2·49	6·14	64·07	15·41	6·15	2·72	1·40	1·64	2·12	0·125	99·815
11-17	1·13	1·80	4·26	65·20	15·46	5·60	2·97	1·98	1·73	2·32	0·140	99·748
57-63	0·63	1·77	3·42	65·69	15·63	6·42	3·42	1·22	1·43	2·13	0·137	99·533

Calculated to Carbonate- and Humus-Free Soil.

Depth of Horizon in Cm.	CO_2 %	H_2O at 100° C. %	Loss on Ignition. %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %	K_2O %	Na_2O %	P_2O_5 %	Total %
0-5.4	—	—	—	68·42	16·36	5·55	2·67	2·33	1·87	2·38	0·163	—
5-12	—	—	—	68·25	16·42	6·55	2·90	1·49	1·75	2·26	0·133	—
11-17	—	—	—	69·98	16·59	6·01	1·64	2·13	1·86	2·49	0·150	—
57-63	—	—	—	69·04	16·43	6·75	2·75	1·28	1·50	2·24	0·144	—

chestnut soil profile from the Government of Jenniseyk (data supplied by GLINKA).[*]

The proportion of humus in the chestnut soils ranges between 1 and 4·5 per cent., the humus layer generally being shallow.   Another profile from the same place gave the following figures:

Depth (Cm.).	Humus (Per Cent.).	Mechanically Bound Water (Per Cent.).	Loss on Ignition (Per Cent.).
0-2	4·02	3·12	5·51
3-14	3·24	3·42	4·50
14-18	2·75	2·63	4·33
19-28	2·12	2·31	4·08
35-45	0·94	1·71	2·48

The proportion of humus in Hungarian chestnut soils varies within practically the same limits.   Those from the neighbourhood of Szabadka, for instance, contain 3·11 per cent. and those from the environs of Szeged 4·60 per cent. humus.   If we contrast the above figures with those showing the humus content of light-brown soils, we shall find a striking difference.

In the light-brown loam soils from the Semirechje Department of Asiatic Russia, for instance, the following results have been obtained by chemical analysis:[†]

Place of Origin.	Depth (Cm.).	Humus (%).	CO_2 (%).
Environs of Tarbogatay, north of Bachti	0-7	1·878	0·859
	10-26	1·210	2·061
	40-45	0·844	4·726
Behind Alakul, near Karaagach ..	0-8	1·750	0·401
	10-22	0·936	1·412
	45-50	0·690	1·964
	(C) 70-80	0·349	1·949
Environs of Taukekulto	0-6	2·04	1·41
	8-24	1·41	3·60
	26-40	0·495	8·04
	(C) 60-80	0·240	17·31
	90-95	0·207	7·42

The humus content of light-brown steppe soils is thus much less than that of chestnut soils, while the surface horizon is already carbonated.

* See GLINKA, K.: op cit., pp. 135-6.
† See GLINKA, K.: op. cit., p. 140.

Physical Characteristics.—From the available data relating to the mechanical composition we can conclude that there is neither mechanical nor chemical eluviation in these soils. Indeed, in general the compactness of structure of brown steppe soils increases with decrease in humus content, the deviation from the crumbly structure of tshernosems increasing accordingly.

Morphological Characteristics.—The humiferous horizon of chestnut steppe soils may be divided into two parts—a relatively loose A_1 horizon of a layered structure, which is not, however, granular like that of southern tshernosems, and a somewhat more compact A_2 horizon, which gradually merges into the parent rock. When these soils become dry, sometimes vertical cracks are formed in both the A_1 and the A_2 horizons at distances of 5-8 cm. Although the surfaces of these cracks are uneven, the lumps of soil in the interstices may be removed, and are found to be prismatic in shape.

Biological Characteristics.—The natural vegetation of brown steppe soils varies according to whether the humidity conditions resemble those prevailing on grassy steppes or those prevailing in dry deserts with scanty vegetation. In more humid regions, for instance, we find *Festuca sulcata*, *Koeleria gracilis* and *K. cristata*, *Bromus inermis* and various *Stipaceæ*; while in more arid regions the predominant plants are *Artemisia* and *Ceratocarpus*. The former group provides a close grass cover, and consequently provides the soil with more organic matter than the scanty and sporadic vegetation of deserts. This accounts for the noteworthy difference in humus content between the chestnut and the light-brown soils. From an agricultural point of view these soils, though not so rich as tshernosems, are relatively speaking not poor in plant food. The prevailing drought usually reduces the yield of crops, for which reason it is usual to employ irrigation and abundant organic manure. These soils are rich in potash and lime, but often need phosphate fertilisers.

Stage V. : Sub-Types of Brown Steppe Soils.

At present we can distinguish only two sub-types of brown steppe soils:

Sub-Type 1 : Chestnut steppe soils.
Sub-Type 2 : Light-brown steppe soils.

There is no sharp line of distinction, and in nature the transition is almost imperceptible. The best indication of the sub-type is supplied by the humus content, which in chestnut steppe soils averages 3·5-5 per cent., and in light-brown steppe soils 1·8-2 per cent.

Stage VI. : Local Varieties.

We have no satisfactory description of these varieties.

Main Type 6 : Grey Steppe Soils.

This type is defined in various ways by soil scientists, principally owing to the grey colour of these soils resembling both that of the salt-crusted soils of dry and torrid deserts and that of heavy leached-alkali soils.   Yet there are decided differences between these soils.

Genetic Characteristics.—The grey steppe soils are the last stage in the transition which leads from the tshernosems to the humus-free, pure mineral soils of dry deserts.

This main type includes only the non-saline grey steppe soils.   The degree of their eluviation and weathering — owing to the lack of humidity prevailing in the regions where they occur—is even less intensive than that of the light-brown steppe soils, while the even scantier vegetation results in their containing less humus which penetrates to a shallower depth.   GLINKA points out further that in former times these soils were called simply wind-blown loess soils.   Exhaustive investigation of the soils of Turkestan has shown, however, that while the parent material is usually loess, the loess-formation was already complete when soil formation began.*   The studies have also shown that the peculiar structure of the upper humus horizon of the grey steppe soils is due to the activity of earthworms, insects and vertebrata (lizards, snakes and turtles).

Dynamic Characteristics.—As a consequence of the slight silicate weathering and humus formation there is also only a small zeolite complex, though the predominant cations in the latter are presumably calcium.   This presumption is supported by the high $CaCO_3$ and gypsum content in the lower horizons, though we have no direct proofs.   The leaching medium is slightly alkaline, but its alkali-salt content is insignificant.

Chemical Characteristics.—Chemical analyses of grey steppe soils show that the silicate complex remains unchanged throughout the whole profile—as in all calcium soils—and the sesquioxides are stable. In this respect, too, they differ from solonetz soils.   Table LXXIV. gives the complete chemical composition of a profile of a soil from a place to the east of Arys.†

Analyses of the water solutions are given in Table LXXV.

Both the insignificant amount of water-soluble salts and the slight degree of alkalinity expressed as $NaHCO_3$ prove that there cannot be any question of an accumulation of alkali salts.

Physical Characteristics.—The few mechanical analyses at our disposal all show that whereas the dominant element in the composition of these soils is silt, there are no traces of mechanical washing-down.‡

Morphological Characteristics.—The upper part of the A horizon is usually greyer and paler than the deeper and browner part, which

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* See GLINKA, K.: *op. cit.*, p. 141.
† See GLINKA, K.: *op. cit.*, p. 145.
‡ See GLINKA, K.: *op. cit.*, p. 142.

TABLE LXXIV

Depth of Horizon in Cm.	0-7.	8-15.	90-100.	137-145.
H_2O (dried at 100° C.)	1·34	1·31	1·44	1·47
Humus	1·61	1·08	0·23	0·21
Chemically bound water	1·02	1·41	0·95	1·41
CO_2	5·10	5·52	10·31	9·34
SiO_2	59·84	59·66	52·86	53·76
Al_2O_3	11·18	11·33	10·25	10·18
Fe_2O_3	5·19	5·35	4·89	5·30
CaO	7·24	7·66	13·06	12·11
MgO	3·08	2·82	3·01	2·82
P_2O_5	0·201	0·23	0·104	0·130
SO_3	0·553	0·160	0·223	0·059
Alkalies calc. as diff.	4·98	4·84	4·11	4·68

TABLE LXXV

Depth of Horizon in Cm.	Dry Residue (Grammes).	Dry Residue after Ignition (Grammes).	Loss on Ignition (Grammes).	Solubility of Humus.	Colour of Solution.	Alkalinity as $NaHCO_3$ (Grammes).
0-7	0·0566	0·0354	0·0212	1/76	Yellowish	0·0344
8-15	0·0576	0·0465	0·0111	1/98	Colourless	0·0344
15-20	0·0445	0·0364	0·0081	—	,,	0·0344
90-100	0·0324	0·0283	0·0041	1/55	,,	0·0344
137-145	0·0365	0·0314	0·0051	1/41	,,	0·0365

TABLE LXXVI

Soil.	Depth in Cm.	> 3 Mm.	3-1.	1-0·5.	0·5-0·25.	0·25-0·05.	0·05-0·01.	< 0·01.
Grey steppe soil in Tsimkent Dep., north from Vrev-skoe.	0-7	—	—	0·06	0·04	19·15	33·04	47·71
	12-26	—	—	0·01	0·02	19·66	33·01	47·30
	50-60	—	—	0·06	0·02	14·77	35·47	49·68
	103-110	—	—	0·02	0·02	27·57	31·89	40·50
	172-180	—	—	—	0·01	17·32	40·85	41·82

resembles the light-brown steppe soils. GLINKA gives the following general description of these soils:* surface horizon slightly stratified and lentil-shaped in structure; owing to dense roots of Gramineæ,

* See GLINKA, K.: op. cit., p. 144.

upper part relatively compact and tenacious, though at a depth of about 5-10 cm. it is already looser in structure; farther down, again, owing to activity of the animals already mentioned, it is porous and easily dug up right down to the stone-hard carbonate horizon.

Biological Characteristics.—Owing to the lack of exact data all we can say is that we have reached the extreme limit of humus-forming vegetation, the soils lying beyond being pure mineral soils.

Stages V. and VI. are still unknown.

Main Type 7: Secondary and Tertiary Calcium Soils.

Here again we have a case of several soil types being comprised in one main type on the common ground that human intervention has changed the whole dynamics of the original soil, shifting it into the dynamic system of calcium soils. These soils might possibly be called artificial soils: TREITZ has indeed called artificial steppe soils those soils formed in regions once covered with forests which have been pressed into the service of agriculture and have changed into typical steppe soils.* The description of these soils given by BALLEN-EGGER† suggests their being tertiary formations; for the areas occupied by them must originally have been covered with steppe soils, later on converted by natural process into brown forest soils. The forests must subsequently have been exterminated and the ground ploughed. Since the present climate is favourable to the formation of steppe soils, the upper part of the forest soils was once more transformed into steppe soils, so that we might call them *regraded steppe soils*.

The method of improvement of low-moor peat soil employed in Prince Esterházy's domain at Kapuvár, which has led to the formation of artificial calcium soils, has resulted in the production of *secondary* calcium soils. The amelioration of alkali soils has also resulted in calcium soils. We see, therefore, that very divergent soil types may be converted into calcium soils by artificial means.

The first question to be answered is whether in principle it is necessary from the point of view of systematics to make a separate main type of soils transformed by artificial means, or whether it would not be better to leave them in the categories to which they originally belonged. Now, should we adopt this latter principle, the soils of Holland, for instance, would not be soils at all; for while on the one hand they have been made fertile by the victory of man's physical strength and brain over the sea, on the other hand the exploitation of the turf-beds for industrial purposes and the mingling of bog-silt and surface sods, combined with liming, have made it impossible to detect the original turf-soil character. And if we exclude from our

* See TREITZ, P.: " Magyarázó az orsz. átnézetes klimazonális talajtérképhez " (Földt. Int., Budapest, 1924).

† See BALLENEGGER, R.: " Adatok magyarországi talajtipusok chemiai összetételének ismeretéhez " (Földt. Int., 1916 Report, p. 556).

soil system soils transformed either by human intervention or by artificial means, or group artificially transformed soils in the categories corresponding to their original character, we should be excluding from our system those soils which are most interesting and most valuable to humanity. On this point my opinion is that, although there may be cases in which human intervention does not—or only transitionally—transform the dynamic equilibrium of the soil, there are other cases where the type is materially changed by human intervention—as, for instance, when hydrogen or sodium soils are transformed into calcium soils. In the latter case the whole dynamic system of the soil is transformed, the result being that the new soils naturally cannot be placed in their original categories.

Genetic Characteristics.—At first sight it would appear impossible to discuss general genetic characteristics when we have to do with the products of the transformation of soils of such divergent origins. Yet all these transformations have one thing in common—viz., that *all the soils are converted into calcium soils.* Consequently only a minor importance attaches to the original character of the soil's dynamics.

Dynamic Characteristics.—During the mineral weathering a zeolite complex saturated principally with calcium is formed, the decomposition of the organic matter resulting in the formation of a humus complex also largely saturated with calcium. In other words, the whole absorbing complex is practically saturated with calcium.

Chemical Characteristics.—The chemical characteristics are far more complicated, for we have to do with the remains of two or even three different dynamic systems. In the case of regraded steppe soils, for instance, the surface horizon betrays the features of a calcium soil—owing to the action of agricultural cultivation and of the steppe climate; for the absorbing complex is approximately saturated with calcium, the water solution of the soils also being rich in calcium cations. The humus of the surface soil is stable, *i.e.* saturated; the soil reaction is either neutral or slightly alkaline, though the alkalinity is due, not to sodium cations, but to $CaCO_3$. But, as the soil was originally a forest soil, we find an accumulation in the B horizon of sesquioxides, while the parent material is loess and crotovines are to be found in it. Naturally, where the soil has another origin, the chemical character of the whole profile changes accordingly.

Physical Characteristics.—All that we can say in general is that owing to the coagulation of the colloidal dispersions the structure comes more and more to resemble the characteristic structure of calcium soils.

Morphological Characteristics.—Since the change in the structure of the soil is due primarily to cultivation, its profile shows considerable divergence between the cultivated upper layer and the uncultivated subsoil, which is far more compact, particularly in the horizon over which the plough-sole passes, as it were stamping the soil. Con-

sequently, the morphological characteristics typical of the original soil conditions are entirely lost.

Biological Characteristics.—These soils are real, improved agricultural soils which have been subjected to treatment by human science to make them as favourable as possible to the development of agrarian production, and therefore to the development of the microflora. The nature of agriculture leads naturally to the plant food supply of the soil being exhausted, so that if no provision is made for its replacement the originally rich soils become poor and worn out. What has to be replaced is not only the plant food, but also humus. Natural steppe soils themselves provide for the optimum accumulation of humus; but where the soil is under agricultural cultivation, and we fail to provide for enrichment with humus, the humus will decrease until there develops an equilibrium corresponding to the residue of dead roots.

Stage V. : Sub-Types of Secondary and Tertiary Calcium Soils.

It will be best to divide the sub-types according to their original dynamics. Today we have no means of surveying all relevant sub-types, and the following enumeration is probably inadequate.

Sub-Type 1 *: Tertiary or regraded steppe soils*, the genetics of which have already been described.

Sub-Type 2 *: Calcium soils artificially formed from peat soils;* found not only in Holland but in Hungary too.

Sub-Type 3 *: Calcium soils formed by liming and deep ploughing from soils originally acid but not turf or peat soils.*

Sub-Type 4 *: Calcium soils formed by suitable reclamation from alkali soils.*

Stage VI. : Local Varieties.

The orographical, hydrographical and climatic conditions probably make their effect felt even more intensively than in the case of natural soils. However, as the parent material of the new soil is the former soil, there may be very material differences in respect of local varieties *according to the measure in which the older soil has become transformed or has resisted the new soil development.* All these circumstances combined determine *the degree of development of the new soil*, which is characteristic of the local varieties.

Main Type 8 : Calvero Soils (Light Chestnut, Dry Forest Soils—as determined by Stremme).

Genetic Characteristics.—These soils occur on the Spanish plateau; according to their present external appearance and their vegetation they may be regarded as steppe soils, though originally they were covered with so-called drought-resistant forests (*Quercus coccifera*, etc.), to be found even today in places. The destruction of the forests, primitive

pasturing and erosion have all contributed to remove the surface humus horizon in most places, the transition horizon remaining mixed with the original stone débris, and reminding us of a light-brown or yellowish steppe soil. For this reason these soils were formerly mistaken for, and called, steppe soils. DEL VILLAR has included them among the lime soils;* designating them as *posthumous* soils, implying that they originally looked different—*i.e.,* they are calcium soils which originally were at least approximately similar to rendzinas, also calcium soils—but in the course of time have been destroyed, the residual transition horizon having come to the surface together with the parent material.

Dynamic Characteristics.—At present the dynamics of these soils are very similar to those of the light-brown steppe soils. Where the original forest has remained, however, the dynamics are similar to those of the sub-tropical rendzinas.

Chemical Characteristics.—Two original Calvero profiles have been analysed in my laboratory (Table LXXVII.). One of these profiles (Md 101) is rich in lime ($CaCO_3$), while the other (Md 102) contains a remarkable proportion of gypsum. The figures of both profiles show that they are typical calcium soils.

TABLE LXXVII

	Md-101.			Md-102.		
	I (a).	I (b).	II.	I (a).	I (b).	II.
Na_2O ..	0·27	0·35	0·30	0·17	0·21	0·04
K_2O ..	0·47	0·52	0·43	0·32	0·18	0·09
MgO ..	7·15	13·92	11·06	1·34	0·71	1·68
CaO ..	30·47	29·99	40·61	23·35	20·50	28·56
MnO ..	0·34	0·05	0·00	0·11	0·07	0·18
Fe_2O_3 ..	2·53	1·53	0·17	3·70	1·75	0·16
Al_2O_3 ..	0·90	0·19	0·07	1·03	0·76	0·34
SO_3 ..	0·20	0·23	0·51	5·69	22·27	40·36
P_2O_5 ..	0·11	0·09	0·06	0·12	0·07	—
CO_2 ..	29·14	34·43	42·74	13·86	4·30	1·09
SiO_2 ..	6·71	10·48	1·20	7·32	6·94	1·16
TiO_2 ..	0·03	0·02	—	0·15	0·10	—
Insoluble residue	10·60	1·52	0·48	27·52	19·02	1·64
Loss on ignition	8·12	3·47	2·11	11·29	16·74	19·58
H_2O (105° C.)	3·05	3·37	0·44	4·34	7·29	5·35
Total	100·09	100·07	100·18	100·40	100·91	100·23

No further description can be given of these soils, which are as yet but little known.

* See DEL VILLAR, E.: *op. cit.*, p. 213.

Soil Order 12 : Sodium Soils
(Main Type 1 : Saline Soils).

The first trace of alkalisation is when we find some accumulation of alkali salts (especially of sodium salts) without the zeolite-humus complex itself becoming alkalised.   These are pure saline soils.

The northern saline soils, which are rich in iron and aluminium sulphates as a result of the reducing action of peat formation—*e.g.* most of the Finnish saline soils—do not in my opinion belong here. They should rather be included among the salty peat soils or the salty, peaty soils.

Genetic Characteristics.—The saline soils belonging to this main type are of very common occurrence in regions where in soils of mixed origin for some reason or other alkali salts—in particular sodium salts— have accumulated.   The accumulation of sodium salts is often accompanied by an accumulation of magnesium salts. and may be due to very different causes.

HARRIS* enumerates a whole series of sources from which the salts of the various saline soils may accumulate.   Scientific literature keeps continually suggesting other possibilities.   If we desire to establish something like a system for these possibilities. we must divide the sources of the salts into four main groups—action of the ocean (oceanic), action of volcanoes (volcanic), weathering, decomposition of dead organic matter.

However, for the salts to accumulate in the soil it is not enough that they should enter the soil or be formed in the soil, *they must also be retained there.*   This may happen in several ways: (*a*) owing to the subsoil water table being continuously so high that the various sodium salts cannot be removed by natural drainage; (*b*) owing to the impervious subsoil preventing leaching out of the sodium salts; (*c*) owing to the evaporation of soil moisture being so rapid that the salts washed down by rain are brought to the surface again by capillarity; (*d*) owing to various combinations of the above three factors.

Dynamic Characteristics.—The dynamic character of saline soils is determined by those chemical. physical and biological phenomena which are dependent upon the qualitative and quantitative changes of the water-soluble alkali salts contained in the soils.

Chemical Characteristics.—The chemical characteristics of saline soils are determined primarily by the chemical composition of the water-soluble salts.

The salts of littoral saline soils originally correspond to the proportionate quantities of sea-water salts.   CLARKE† gives the following average composition of sea water:

* See HARRIS, F. S.: " Soil Alkali, its Origin, Nature and Treatment." (New York, 1920).
† See CLARKE, F. W.: "The Data of Geochemistry" (U.S. Geol. Survey Bull., No. 616, 1916, pp. 22-35).

NaCl	..	..	..	..	..	..	77·76 per cent.
MgCl₂	..	..	..	..	..	..	10·88 ,,
MgSO₄	..	..	..	..	..	..	4·74 ,,
CaSO₄	..	..	..	..	..	..	3·60 ,,
K₂SO₄	..	..	..	..	..	..	2·46 ,,
MgBr₂	..	..	..	..	..	..	0·22 ,,
CaCO₃	..	..	..	..	..	..	0·34 ,,

<center>Total ..   .. 100·00 per cent.</center>

My own investigations* and those of HILGARD† (Table LXXVIII.) have provided the chemical data characteristic of the salts of alkali soils found in various parts of the world.

The data in Table LXXIX. showing the salt composition of a Russian "solontshak" soil are from GLINKA.

The salt content of saline soils varies considerably. We may nevertheless say that the bulk of salts are sodium salts combined with a certain quantity of magnesium salts. The anions occurring most frequently are Cl, SO₄ and carbonates, nitrates occurring only exceptionally—usually in places where there is decomposition of organic matter. The carbonates are present partly as normal carbonates, partly as bicarbonates. In some cases the composition of the salts is very simple, in others very complex.

Physical Characteristics.—The mechanical composition of saline soils may vary considerably—as is only natural when we consider the possibilities of formation. Sodium salts may, however, exercise a considerable effect upon the texture of the soil. In this respect there is a considerable difference between the effect of alkali carbonates and the carbonate-free sodium salts; for while the former increase, the latter decrease the degree of dispersion of the soil.

Morphological Characteristics.—The morphological features of saline soils may vary considerably; for while on the one hand the original soils themselves may differ materially in their morphology, on the other hand the quality, quantity and even the vertical distribution of the salts can give rise to so many varieties that there can be no talk of general morphological characteristics. The morphology of a saline soil usually resembles that of the original soil or is entirely structureless.

Biological Characteristics.—The most characteristic feature of these soils is the saline vegetation, which—though it may vary from place to place—within any given district shows a close connection with the salt content and salt quality of the soil.‡

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* See SIGMOND, A. A. J. DE: "Hungarian Alkali Soils and Methods of their Reclamation " (Berkeley, Calif., 1927), pp. 106 and 110.

† See HILGARD, E. W.: " Soils " (New York, 1910), pp. 442-53.

‡ See SIGMOND, A. A. J. DE: " Hungarian Alkali Soils," etc., p. 60.

TABLE LXXVIII

| | Irrigated Land at Békéscsaba (Hungary). | | Tetétlen-puszta (Hungary). | Reh (India). | Trona (Egypt). | Tulare (Cal., U.S.A.). | Imperial Valley (Cal., U.S.A.). | Rocky Ford (Colorado, U.S.A.). |
	Field 38.	Field 17.						
KCl ..	9·78	1·91	—	—	—	—	—	—
K_2SO_4	13·26	5·65	7·70	—	—	3·95	1·15	13·74
NaCl	5·70	11·57	49·40	18·6	14·0	14·75	31·82	11·53
Na_2SO_4	—	—	2·65	58·5	38·3	25·28	8·21	17·36
$NaNO_3$	—	—	—	—	—	19·78	—	—
$NaHCO_3$	—	—	2·12	—	—	—	—	—
Na_2CO_3	67·57	75·06	32·93	22·9	47·7	32·58	0·58	5·53
Na_3PO_4	—	—	—	—	—	2·25	—	1·65
$MgCl_2$	—	—	—	—	—	—	2·81	5·76
$MgSO_4$	—	—	—	—	—	—	—	44·43
$CaCl_2$	—	—	2·19	—	—	—	—	—
$CaSO_4$	3·69	4·32	3·01	—	—	—	58·42	—
$FeSO_4$	—	1·49	—	—	—	1·41	—	—
$(NH_4)_2CO_3$ ..	—	—	—	—	—	—	—	—
Total ..	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

TABLE LXXIX*

Depth in Cm.	Dry Residue.	Loss on Ignition.	In-organic Residue.	Pb_2O_3	CaO	MgO	K_2O	Na_2O	Alkalinity.		SO_3	Cl
									Na_2CO_3	$Na(HCO_3)_2$		
Efflorescence	0·813	0·011	0·802	0·0020	0·0402	0·0013	0·0111	0·2997	0·0015	0·0565	0·430	0·0070
1-4	5·369	0·062	5·303	0·0056	0·1126	0·0078	0·0249	2·0938	0·0024	0·0419	2·948	0·0310
10-20	1·982	0·095	1·887	0·0020	0·1107	0·0343	0·0291	0·7378	0·0004	0·0259	0·543	0·5810
103-110	0·790	0·009	0·780	0·0012	0·0114	0·0079	0·0076	0·3576	0·0015	0·0341	0·334	0·2671
130-140	0·378	0·001	0·377	0·0016	0·0049	0·0055	0·0058	0·1887	0·0025	0·0372	0·815	0·1331

* Water extract of a "solontshak" (Syr-Darja region).

Stage V. : Sub-Types of Saline Soils.

As there is a great divergence in respect of the origin and quality of saline soils, it is extremely difficult to give any exact description of the general characteristics of the sub-types. We may nevertheless, on the basis of the general characteristics of the main type, differentiate the following sub-types:

1. *Saline soils containing exclusively or principally sulphates* (such as, for instance, the soils found in the environs of Budapest or at Billings, Montana).

2. *Saline soils containing exclusively or principally chlorides* (in the neighbourhood of salt mines, littoral saline soils, etc.).
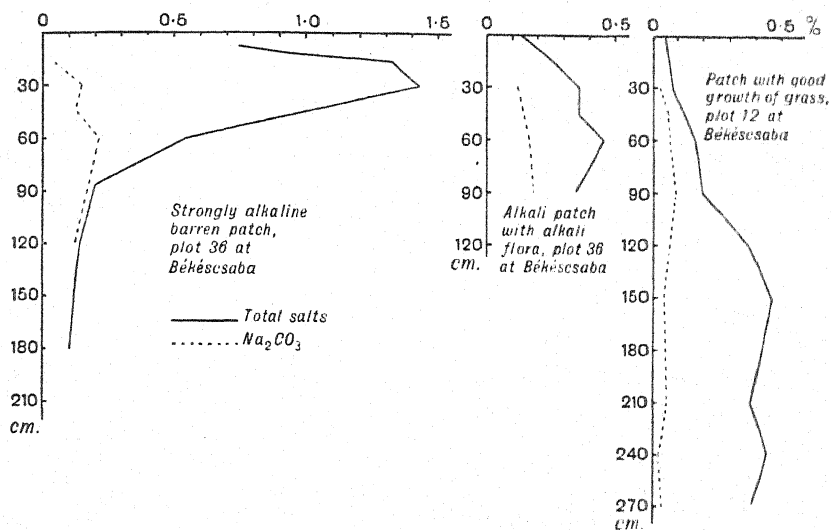
Fig. 20.

3. *Saline soils containing sulphates and chlorides* (*e.g.*, in the valley of Pecos, New Mexico).

4. *Saline soils containing sulphates and carbonates* (*e.g.*, the Békéscsaba soils in Hungary).

5. *Saline soils containing chlorides and carbonates* (environs of Szeged, Hungary).

6. *Saline soils containing sulphates, chlorides and carbonates.*

7. *Soils containing principally soda* (*e.g.*, the soils in the region lying between the Danube and the Tisza).

Stage VI. : Local Varieties.

Probably in no other order of soils are the local varieties so multifarious as in the case of saline soils. Owing to their high solubility, the salts move very easily in the soil. HILGARD pointed out that in

saline soils the vertical and horizontal distribution of the salts may vary considerably. Fig. 20 illustrates a few types of the vertical distribution of salts in irrigated alkali land in Békéscsaba.

The Békéscsaba land shows also that in a relatively small area there may be enormous variations in salt content (Fig. 3). The flora of the alkali land at Békéscsaba accords with its salt content. The interdependence of salt content and vegetation ascertained by investigation has enabled me to formulate a practical classification of the Hungarian alkali soils.

First of all I formulated the following classification based upon the total salt content:

		Total Salt Content.
Class I.	.. ..	0-0·10 per cent.
Class II.	.. ..	0·10-0·25 ,, ,,
Class III.	.. ..	0·25-0·50 ,, ,,
Class IV.	.. ..	More than 0·50 per cent.

Since plants are peculiarly sensitive towards the soda content, I have determined the following practical limits in this respect :

		Soda Content.
Class I.	.. ..	0-0·05 per cent.
Class II.	.. ..	0·05-0·10 ,, ,,
Class III.	.. ..	0·10-0·20 ,, ,,
Class IV.	.. ..	More than 0·20 per cent.

Finally, in order to combine the two classifications, I have taken the classification by total salt content as the numerator and that by total soda content as the denominator, the result being as follows:

Class I.	.. ..	I/I		
Class II.	.. .. Sub-class A	II/I	or	I/II
,, ,,	.. .. ,, B	II/II	,,	III/I
Class III.	.. .. ,, A	III/II	,,	II/III
,, ,,	.. .. ,, B	III/III	,,	IV/II
Class IV.	.. .. ,, A	IV/III	,,	III/IV
,, ,,	.. .. ,, B	IV/IV		

As this combined classification has proved to be in harmony with the demands of the plants grown or cultivable on alkali soils and in general with the reclamation of the alkali lands in Hungary, we may call it a *practical biological classification.**

Main Type 2: Salty Alkali Soils.

Some of these soils are shown in Figs. 21 and 22 (after photographs by DR. ARANY). Fig. 21 illustrates a limy soda patch of the sandy territory near Nyiregyháza in Hungary. The white spot bare of vegetation shows salt efflorescence. Another type of salty alkali soil, at

* See SIGMOND, A. A. J. DE: " Hungarian Alkali Soils," etc., p. 59.

Hajdudorog, Hungary, is illustrated in Fig. 22. This is also a salty alkali soil, but quite different in appearance from the former soil. The white spots—even though they contain some sodium salts
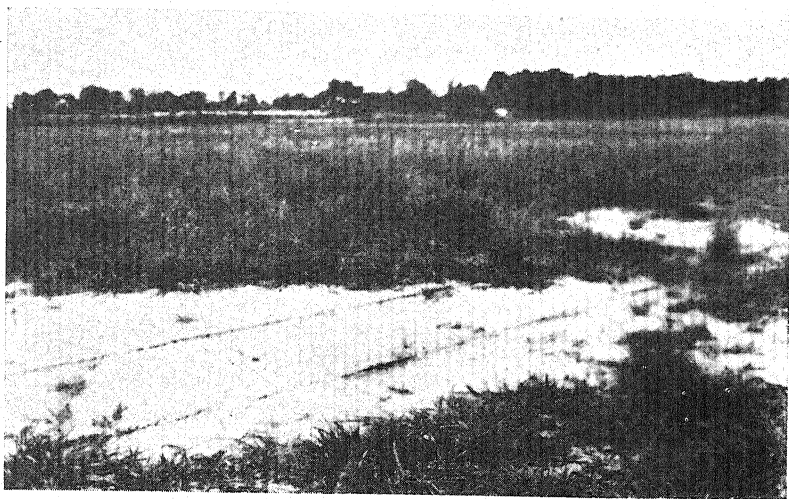
FIG. 21.
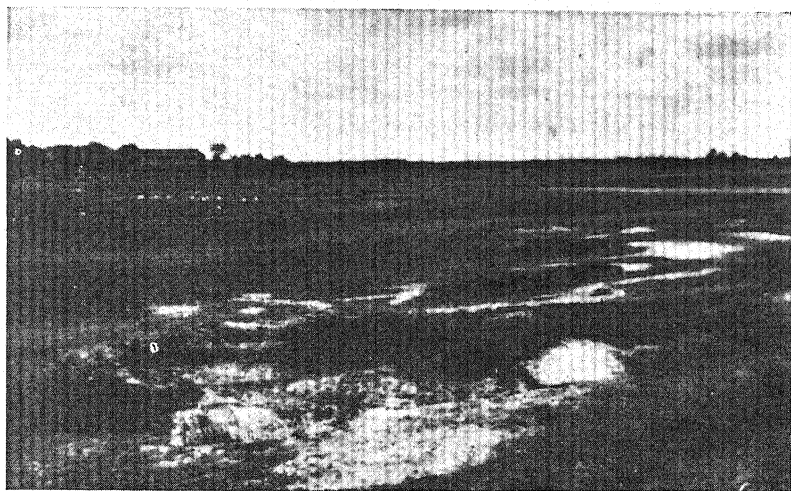
FIG. 22.

and also soda—are chiefly clayey crust formations and not true efflorescences.

Genetic Characteristics.—The second stage of alkali soil formation

is when, through the action of sodium salts, the absorbing complex is entered by a quantity of sodium cations sufficient considerably to increase the dispersivity of the colloids. This effect is not appreciable as long as there is an abundant quantity of NaCl or Na$_2$SO$_4$ in the soil. But as soon as the salt content has to some extent been reduced, the absorbing complex is peptised and is able to fill the interstices in the soil sufficiently to prevent percolation. We have found that when the sodium equivalents in the S complex exceed 10-15 per cent. the dispersing effect of the sodium cations becomes appreciable.

Dynamic Characteristics.—The dynamics of salty alkali soils closely resemble those of simply saline soils. In practice the difference is usually imperceptible, and does not make its appearance until we ameliorate the soils—*e.g.*, by leaching. For the saline soils are easily washed out, giving soils resembling other non-saline soils of similar structure. In the case of salty alkali soils, however, during leaching we often observe a deterioration, for the soil becomes less and less permeable with the advance of the leaching.

Chemical Characteristics.—The dominant feature of salty alkali soils is the high proportion of exchangeable sodium cations and the large amount of water-soluble sodium salts. According to investigations made at Hungary, the percentage of exchangeable sodium equivalents calculated to the S-value is not less than twelve, that of the total salt being more than 0·20 per cent., for which reason these alkali soils belong to Class III. or Class IV.—or to their respective sub-classes.

These processes, however, transform the whole chemical composition of the soil profile, for the soil is practically without interruption exposed to the eluviation of alkali salt solutions of a concentration varying with the moisture conditions. These solutions follow the direction of the soil moisture, percolating downwards or rising by capillarity and washing through the soil horizons in both directions. The salty soil solutions dissolve the CaCO$_3$ and CaSO$_4$, the result being that the calcium salts are washed down from the upper into the lower horizons, where they accumulate. The interaction of the CaCO$_3$ and the NaCl or Na$_2$SO$_4$ forms Na$_2$CO$_3$ and CaCl$_2$ or CaSO$_4$ respectively. GEDROIZ questioned the possibility of soda being formed in this way in soils, attributing its formation to the hydrolytic decomposition of the sodium complex.* There is no doubt that soda can form in the manner suggested by GEDROIZ, but only after the bulk of the sodium salts have been leached out. The Hungarian soda soils prove just the contrary; for despite a high soda content they contain also considerable quantities of sodium chloride or sodium sulphate—thus contradicting GEDROIZ's theory. More recently this question has

* See GEDROIZ, K. K.: "Colloidal Chemistry as related to Soil Science," a work originally published in Russian (1912) and not translated into English until after the Great War.

been reinvestigated by CUMMINS and KELLEY,* whose experiments have once more shown† that when non-alkali soils are treated with sufficiently concentrated neutral sodium salt solutions, the sodium cations gradually exchange with the calcium cations, while the soil thus transformed shows an alkaline reaction after removal of the sodium salts.   This may be explained as due to the absorbed sodium being hydrolysed by water, temporarily forming a small quantity of NaOH which, combining with the CO_2 of the soil, produces Na_2CO_3. This is the manner of soda formation as determined by GEDROIZ. The reaction is certainly correct and explains why alkali soils that are only slightly salty can give an alkaline reaction.   According to this reaction no considerable quantity of Na_2CO_3 can form in the soil unless the neutral sodium salts (NaCl and Na_2SO_4) are first removed. According to CUMMINS and KELLEY's experiments the original concentration of salts has to be reduced to about one-half to enable leaching to produce an alkaline reaction.   To allow the formation in this manner of any considerable quantity of soda it is, however, necessary to wash through with increasing quantities of water the soil gradually freed from salts.   According to the data shown by experiments known to us, this quantity is far less than that often found in Hungarian alkali soils.   In my opinion the mechanism of soda formation suggested by GEDROIZ merely explains why, when mixed with pure water, sodium soils which are otherwise free of carbonates, and therefore of soda, produce an alkaline reaction, and it points to the possibility of Na_2CO_3 accumulating in the subsoil as a result of leaching. We often find cases of this kind in leached alkali soils.   It is therefore indubitable that a certain amount of soda may be formed in sodium soils even when they are free of carbonates.   According to HILGARD's theory this is impossible, because one of the forming factors—$CaCO_3$— is lacking.   Another point ascertained as a result of the experiments made by CUMMINS and KELLEY is that if we mix a sodium soil free of carbonates with neutral and soluble calcium salts (e.g., with $n/10$ calcium chloride), the alkalinity of the sodium soil disappears completely.   CUMMINS and KELLEY drew the erroneous conclusion that $CaCO_3$ is not only unnecessary but may actually be detrimental to soda formation because, as shown by HILGARD's equations, what results is either $CaCl_2$ or $CaSO_4$, which both suppress the hydrolysis of the sodium soil and consequently soda formation too.   In my opinion, however, all that this proves is that in the case of calcareous saline soils the soda found in the soil cannot be formed as suggested by GEDROIZ, but only in the manner ascertained by HILGARD.   In the case of saline soils free of carbonates the theory suggested by GEDROIZ can be applied.

* See CUMMINS, A. B., and KELLEY, W. P.: "The Formation of Sodium Carbonate in Soils" (Cal. Agr. Exp. Station. Technical Paper, 3, 1923). Cf. SIGMOND, in Mezőgazdasági Kutatások, Vol. II., 1929, p. 272.

† I had ascertained this fact already in 1916 (in Math. és Természettud. Értesitő, Vol. XXXIV., p. 279).

To sum up, my own experience does indeed endorse the results obtained by GEDROIZ, CUMMINS and KELLEY, but it would appear that in the case of natural sodium soils a considerable quantity of soda is found only in those alkali soils which contain also a considerable quantity of $CaCO_3$. In these soils, besides soda, we often find large quantities of neutral sodium salts—which, according to GEDROIZ, should prevent the formation of soda. Hence the soda formation cannot be explained except by HILGARD's theory.

HILGARD distinguishes two kinds of alkali soils—white and black. The white soils contain only neutral salts, the black soils contain soda as well. This differentiation is based upon the fact that if the soil is humous and also contains soda, the soda dissolves the humus, producing a brown efflorescence. Where the soil does not contain much soda, the salts consisting chiefly of $NaCl$ and Na_2SO_4, the
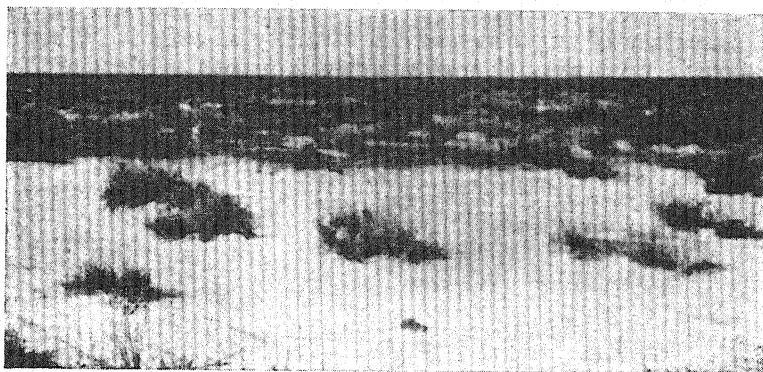
FIG. 23.

efflorescence is white. Fig 23 shows a white alkali soil from Fresno in California (photo by DR. ARANY).

In the alkali soils of the Hungarian lowlands (viz., in the heavy alkali lands lying on the banks of the River Tisza) the bulk of the salts is Na_2SO_4, with here and there some Na_2CO_3 and $NaCl$, and also water-soluble magnesium salts.

Two distinct types of these heavy alkali soils are shown in the photographs by DR. ARANY reproduced in Figs. 24 and 25. In the most salty areas of these alkali lands the plant of most frequent occurrence is the *Camphorosma ovata*, patches of which are shown in Fig. 24.

In alkali bottom-lands in which in spring the water stagnates for some time and in the dry summer season evaporates, the clay cracks and develops a mosaic-like pattern on the surface—as shown in Fig. 25.

In the soda soils found extensively in the region between the Danube

and the Tisza the salts are mainly Na_2CO_3 and $NaHCO_3$, with here and there some $NaCl$ and even Na_2SO_4.

In my monograph on Hungarian alkali soils already referred to
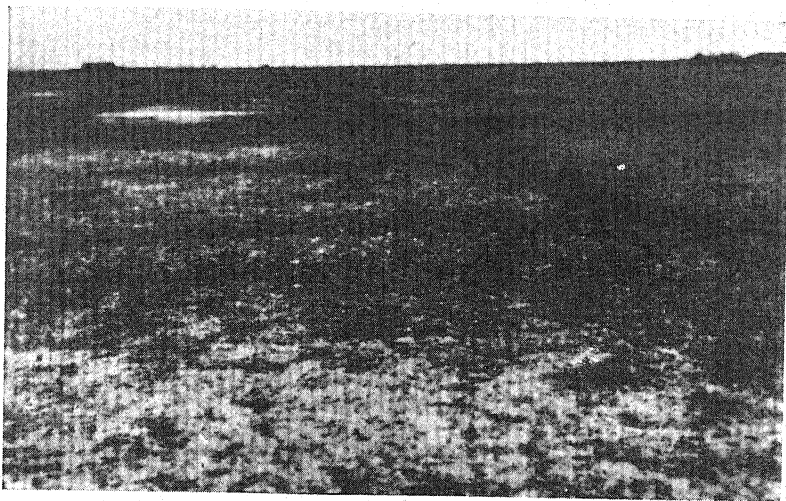
FIG. 24.
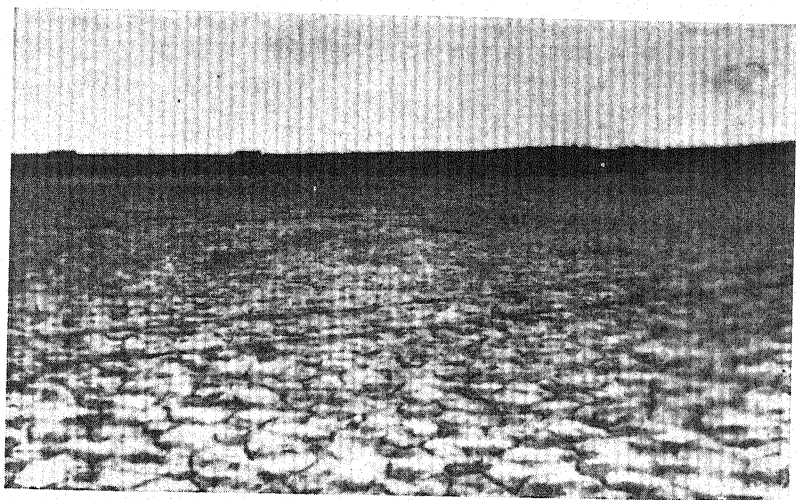
FIG. 25.

there are numerous data relating to the composition of the hydro-chloric extracts of those soils.*

Physical Characteristics.—The mechanical composition of salty alkali soils may vary considerably.

* See pp. 99 ff.

The physical properties of heavy alkali soils depend largely upon the quantity and quality of the salts and upon the degree of alkalisation of the soil. My studies of Békéscsaba soils, which helped me to explain the process of alkalisation,* showed that in impermeable alkali soils there are far larger quantities of exchangeable sodium than in the permeable alkali soils of better quality.

Morphological Characteristics.—The salty alkali soils in many respects resemble the Russian " solontshak " soils, as usually they have no special structure. A soil of this kind is shown in the profile
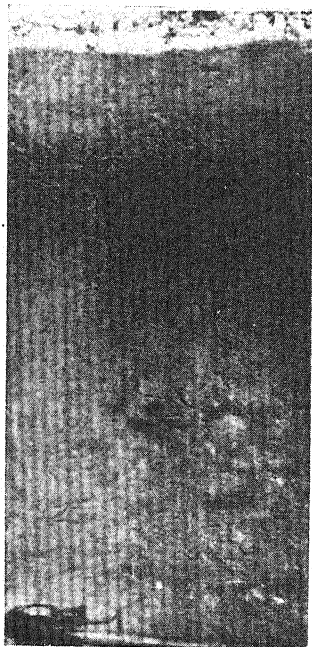
FIG. 26.   FIG. 27.

reproduced in Fig. 26. A close study of the Russian literature, however, shows that the term " solontshak " does not correspond exactly with the salty alkali soils. For, although the salty alkali soils are very often structureless, we do find them with eluvial and illuvial horizons possessing definite structure. This latter type is illustrated in Fig. 27. The horizons are not indeed so distinct as in the leached alkali or Russian " solonetz " soils, but their structure betrays many features in common with the " solonetz " soils.

Biological Characteristics.—Practically the same as in the saline soils. Stages V. and VI. are also analogous to the saline soils.

* See SIGMOND, A. A. J. DE: Math. Természettud. Értesitö, Vol. XXXIV. (1916), pp. 311-12.

Main Type 3 : Leached Alkali Soils.

Genetic Characteristics.—We have already seen that the formation of saline and salty alkali soils is characterised by an accumulation of alkali—in particular of sodium—salts, usually due, among other things, to an excessively high water level. Now, if the level of the ground water sinks—though only periodically—or if we drain off the salty ground water, there begins a process of intensive leaching out, the first phase of which is the falling below 0·10-0·15 per cent. of the quantity of water-soluble salts. During this process the absorbing complex loses none of its sodium, but the whole profile changes to that of an alkali soil (" solonetz ") with a structure. Fig. 28 shows a profile of this kind from Tiszarof (Hungary) after a photograph by Dr. Arany.

Dynamic Characteristics. — Let us suppose that the surplus moisture has been drained off from a salty alkali soil, the soil being then rewetted and drained repeatedly. The result will be that the sodium salts are more or less leached out, while at the same time the dispersivity of the soil constantly increases. If the soil from time to time becomes dry, we have imitated the process occurring in nature. During the periods of dryness the soluble compounds which are leached down but not washed out will rise again to a certain level. For, though the sodium salts follow closely the movement of the soil moisture, the less soluble salts—*e.g.*,

FIG. 28.

$CaCO_3$ and $CaSO_4$—follow the sodium salts more slowly in proportion to the decrease in their solubility. To this is due the fact that, when leaching follows a downward direction, the $CaSO_4$ penetrates deeper than the $CaCO_3$, which is leached from above, whereas when the soil solutions move upwards, the $CaSO_4$ rises higher than the $CaCO_3$. This results in the $CaSO_4$ and $CaCO_3$ precipitating out of the saturated soil solutions round the primary foci of crystallisation. In the subsoil of steppe soils, for instance, we find usually the gypsum horizon deeper than the lime horizon, whereas in leached alkali soils the reverse is the case. For in salty alkali soils the level of the ground water was originally high, salt

accumulation having begun with the drying-up for some reason of the upper horizons, so that the movement of the soil solutions started upwards from the water level. $CaCO_3$ does not rise very high and precipitates; it is followed by $CaSO_4$, and only sodium salts reach the upper layers. During the following leaching the salts do indeed dissolve in the reverse order; but while the foci of crystallisation formed previously do not dissolve entirely, the process of leaching cannot go beyond the former water level, and there is consequently no opportunity for precipitation until during a new dry period the movement of the solutions becomes an upward one again. Thus the horizons above the gypsum horizon become more alkalised, but not necessarily more saline; whereas in the case of Hungarian steppe soils, for instance, we find a slight alkalisation below the gypsum horizon. At first it would appear as if the sodium salts had entered the soil from below, but actually the sodium salts formed or collected on the surface penetrate downwards into the lower horizons—just as in the case of Hungarian steppe soils. But, whereas in the case of the steppe soils the subsoil is permeable, and the leached salts are carried right away, in the case of alkali soils the subsoil is impermeable, so that the surplus salts cannot be removed and during evaporation reach the surface again.

The result of this repeated washing through of the upper horizons by sodium-salt solutions is that *the degree of alkalisation may be much higher than in the earlier phases.* But even if this does not happen in each single case, the advance in the leaching of the sodium salts is accompanied by a corresponding increase in the dispersivity of the absorbing complex, while as a consequence of downward percolation of the colloidal solutions the B horizon becomes more and more impermeable. This is the origin of the so-called " *hard-pan* " *horizon— the horizon which is impervious alike to water and to air, separating off almost hermetically the upper horizons of alkali profiles from the lower horizons.* The downward movement of surface water is possible only through the cracks formed in dry periods, these cracks serving as channels for the washing down of a part of the upper leached greyish horizon, which then mottles the cross-section of the lower and darker horizons and covers the surfaces of the dried clods with a sugar-like coating. This is the origin of *the typical structure of alkali soils or what the Russians call " solonetz."* Recently KELLEY and others have described soils with a " solonetz " structure in which the proportion of exchangeable sodium is negligible. These soils they call " magnesium-solonetz " soils. If used in this sense the term " solonetz " refers to the structure of the soil only and does not correspond to the original idea expressed by the Russian word.

Chemical Characteristics.—We have very few data relating to a complete analysis of structural alkali soils. GLINKA has published* the total chemical composition of a " solonetz " profile soil from the

* See GLINKA, K.: " Typen der Bodenbildung," p. 198.

TABLE LXXX

Percentage in Air-Dry "Solonetz" Soil (Total Analysis by Fusion).

Horizon (Depth in Cm.)	CO₂	H₂O (105° C)	Loss on Ignition.	SiO₂	Al₂O₃	Fe₂O₃	CaO	MgO	K₂O	Na₂O	N	Total.
A₁ (0-3)	—	1·09	9·29	66·48	11·98	3·87	1·57	0·99	2·35	2·46	0·070	99·27
A₂ (15-21)	—	1·11	3·42	71·89	12·01	3·79	2·29	0·31	2·29	2·58	0·096	98·706
B₁ (21-29)	—	2·72	5·37	66·36	14·76	4·71	2·89	0·74	2·60	1·98	0·066	99·496
B₂ (32-41)	0·58	2·00	7·86	62·04	15·48	5·23	3·25	0·28	2·42	2·77	0·114	99·518

Percentage in Humus- and Carbonate-Free Soil.

	CO₂	H₂O	Loss on Ignition.	SiO₂	Al₂O₃	Fe₂O₃	CaO	MgO	K₂O	Na₂O	N	Total.
A₁	—	—	—	73·29	13·21	4·27	1·73	1·09	2·59	2·71	—	—
A₂	—	—	—	74·43	12·44	3·92	2·37	0·32	2·37	2·67	—	—
B₁	—	—	—	70·12	15·60	4·98	3·05	0·78	2·75	2·09	—	—
B₂	—	—	—	68·31	17·05	5·76	2·76	0·31	2·66	3·05	—	—

Government of Yeniseyk, together with the values calculated to the purely mineral part. His figures are shown in Table LXXX.

GLINKA concluded that there had been an accumulation of SiO_2 and a decrease of bases and sesquioxides in the upper horizons (A_1 and A_2). The bases and sesquioxides were found to have accumulated most particularly in horizons B_1 and B_2.

The chemical composition of the hydrochloric extract of a typical " solonetz " soil and that of the absorbing complex can be best illustrated by giving the data for an alkali soil from the Hortobágy region (Hungary). The composition of the hydrochloric extract of the profile is given in Table LXXXI.

TABLE LXXXI

Horizon.	Percentage calculated to Soil dried at 105° C.							
	A	B_1	B_2	B_3	C_1	C_2	C_3	D
Na_2O	0·90	2·32	3·00	1·96	0·78	0·81	0·67	0·89
K_2O	0·36	0·43	0·55	0·70	0·27	0·29	0·26	0·29
CaO	0·63	0·77	1·09	0·69	10·26	16·00	14·53	14·40
MgO	0·27	0·70	0·67	1·65	1·42	0·23	0·24	0·35
MnO	—	—	—	—	0·02	0·98	1·04	0·78
Al_2O_3 ..	3·60	5·77	8·15	8·33	6·65	6·63	8·95	8·25
Fe_2O_3 ..	0·57	3·32	6·81	7·00	4·14	3·60	4·63	4·50
SO_3 ..	0·18	0·26	0·58	0·46	0·01	0·23	0·27	0·17
P_2O_5 ..	0·21	0·13	0·12	0·20	0·15	0·07	0·05	0·04
CO_2	—	—	—	—	7·20	11·55	10·62	10·45
Soluble SiO_2 ..	5·83	10·88	20·75	21·20	12·94	12·75	13·50	13·36
Loss on ignition	10·94	2·02	2·24	2·25	1·96	1·46	1·61	2·15
Insoluble residue	76·50	73·75	55·75	55·15	54·80	46·00	44·00	44·95
Total ..	99·95	100·35	99·71	99·59	100·60	100·60	100·37	100·59

The first thing shown by the above figures is that the insoluble residue decreases with depth. This corresponds on the whole to the decrease with depth of the total SiO_2 of " solonetz " soils, as most of the part insoluble in hydrochloric acid is composed of quartz. It is, however, equally clear that the proportion of the soluble SiO_2—which originates principally from decomposed silicates—is least in the upper horizon, reaching its maximum in the B horizon, as do also the soluble Al_2O_3 and Fe_2O_3. We see, then, that the sesquioxides and the soluble SiO_2 have been washed down into the B horizon, partly as free oxides and silicic acid gels and partly as complex gels and zeolite-like compounds.

The data given in Table LXXXII. show that the solubility of the SiO_2 and Al_2O_3 in 5 per cent. KOH solution is far less than in HCl.

Of the bivalent and monovalent bases the CaO reaches its maximum in the C_2 horizon, the MgO and K_2O in the B_3 horizon, and the Na_2O

TABLE LXXXII

Horizon.	Al_2O_3 % dissolved by HCl.	Al_2O_3 % dissolved by 5 % KOH.	SiO_2 % dissolved by HCl.	SiO_2 % dissolved by 5 % KOH.
A..	3·60	0·54	5·83	1·54
B_1	5·77	0·58	10·88	1·70
B_2	8·15	0·35	20·75	1·87
B_3	8·33	0·32	21·20	2·04
C_1	6·65	0·50	12·94	1·51
C_2..	6·63	0·48	12·75	1·49
C_3..	8·95	0·45	13·50	1·55
D ..	8·25	0·44	13·36	1·58

in the B_2 horizon, showing that all have alike been leached downwards. Of the acid residues the SO_3 reaches its maximum in the B_2 horizon, the P_2O_5 in the A and the CO_2 in the C_2 horizon, where there is an accumulation of $CaCO_3$. The SO_3 residue concentrated in the B_2 and B_3 horizons represents the gypsum accumulation horizon.

The chemical character of the hydrochloric extract is best shown by the data of Table LXXXIII.

TABLE LXXXIII

Horizon.	Percentage of mg. Equivalents, calculated to that of the Total Cations.							
	A	B_1	B_2	B_3	C_1	C_2	C_3	D
Total mg. Equiv. of Cations.	306·1	607·9	916·7	940·1	1008·4	1159·9	1283·4	1234·7
Na^I ..	9·5	12·14	10·56	6·74	2·50	2·22	1·68	2·35
K^I ..	2·5	1·53	1·30	1·58	0·57	0·55	0·43	0·49
Ca^{II} ..	7·3	4·60	4·34	2·65	36·08	48·93	40·45	41·38
Mg^{II} ..	4·4	5·70	3·63	8·95	6·95	4·94	0·95	1·48
Mn^{II} ..	—	—	—	—	0·05	2·38	2·29	1·76
Fe^{III} ..	7·0	20·44	27·92	28·05	15·35	11·59	13·43	13·60
Al^{III} ..	69·3	55·48	52·35	52·00	38·50	33·39	40·77	38·84
SO_4^{II} ..	1·5	1·06	1·58	1·22	0·02	0·49	0·52	0·32
PO_4^{III} ..	3·5	0·90	0·55	0·90	0·63	0·25	0·16	0·14
CO_3^{II} ..	—	—	—	—	32·33	45·03	37·37	38·24
SiO_4^{II} ..	95·00	98·04	98·04	97·88	67·02	54·23	61·95	61·30
SiO_2 surplus	1·47	1·83	7·32	7·33	2·66	3·21	1·42	1·87

The above data show that, numerically, the soil is definitely a sodium soil, for in the A_1, B_1 and B_2 horizons sodium is the most prominent of both the monovalent and bivalent cations. Moreover, in the B_3 horizon, though the percentage of magnesium equivalents is higher than that of sodium, the amount of the latter is nevertheless relatively higher than in the C horizons. In this respect the profile of an alkali soil differs materially from that of hydrogen soils, in which sodium usually plays a very subordinate part.

The most characteristic feature is, however, the quantity of exchangeable cations, the data relating to which will be found in Tables LXXXIV. and LXXXV. (same profile as above).

TABLE LXXXIV

Horizon.	mg. Equivalents of Exchangeable Cations in 100 Grammes Dry Soil.				
	Ca	Mg	K	Na	Total (S).
A	6·2	5·5	1·2	7·7	20·6
B_1	9·6	6·1	1·0	14·6	31·4
B_2	10·3	7·3	0·9	23·8	42·3
B_3	9·9	9·5	1·0	20·5	40·9
C_1	14·4	8·8	1·8	14·6	39·6
C_2	15·5	8·6	2·9	12·4	39·1
C_3	16·1	8·0	2·4	14·0	40·5
D	15·9	8·4	2·0	12·8	39·1

TABLE LXXXV

Horizon.	Percentage of Exchangeable Cations, calculated to S = 100.			
	Ca	Mg	K	Na
A	30·1	26·7	5·8	37·4
B_1	30·6	19·7	3·2	46·5
B_2	24·4	17·2	2·1	56·3
B_3	24·2	23·2	2·4	50·2
C_1	36·4	22·2	4·5	36·9
C_2	38·9	22·0	7·4	31·7
C_3	39·8	19·7	5·9	34·6
D	40·6	21·5	5·1	32·8

The data also show that the whole profile is that of a sodium soil, for the proportion of the Na equivalents in percentage of S value far exceeds 12-15 per cent.

However, leached alkali soils easily become degraded in the course of leaching and are transformed into " soloti " soils. In the case under discussion the A horizon—as shown by the data of Table LXXXVI.—may be described as already degraded. That is shown in particular by the low pH value of the surface horizon and by its high hydrolytic acidity.

In this connection I must point out that the hydrolysis observed by GEDROIZ is so slight that even the most thoroughly alkalised B_2 horizon failed to give a positive reaction for Na_2CO_3. In the A horizon soda formation was probably prevented by the high concentration of H ions, but this is not very probable in the case of the B_1 and B_2 horizons. This proves that soda formation according to GEDROIZ's theory is by no means so easy as to warrant us in attributing the considerable quantities of soda found in the sodium soils exclusively to that process. And it is also proved that measurable quantities of soda are only found where there is abundant $CaCO_3$—i.e., from the C_1 horizon downwards.

Physical Characteristics.—A characteristic feature of leached alkali soils is that the B horizons—produced by illuviation from above—contain a larger proportion of clay than the A horizons. This is frequently the case in salty alkali soils too; it is most highly developed in the " solonetz " soils, as may be seen from the soils with a columnar structure from the Turgey region (Russia), the data relative to which are given by GLINKA* (see Table LXXXVII.).

The data show that in the B horizons the fractions with a diameter of 0·05-0·0015 mm. and less than 0·0015 mm.—i.e., the clay fraction—are greater than in the A horizon. The physical behaviour of leached alkali soils in general is very unsatisfactory alike for cultivation and for plant growth—often, indeed, much worse than that of salty alkali soils. When it rains, they very slowly take up water, and even after a heavy rain they become wet only to a depth of 1-2 mm., below which they are hard and dry. This is due to the considerable swelling of the colloids and to the resulting increase of volume, which closes all the pores and makes them impervious. This explains also why in the dry state the pore volume of alkali soils is less than their water capacity.† The same cause is responsible for their being scarcely permeable. Another characteristic feature of these soils is that if we mix them with a large amount of water, we get a turbid solution which does not become clear even after six months. This is due to the sodium in the humus-zeolite complex exercising a peptising effect, though formerly it was attributed to the influence of soda. To the same cause may be attributed also the physical phenomenon that when mixed with water an alkali soil immediately deflocculates, whereas when dried it becomes hard as a stone and cracks to a great depth. These properties are seen in practically all, though most

* See GLINKA, K.: " Die Typen der Bodenbildung," p. 197.
† See SIGMOND, E.: Vízügyi Közl., Vol. III., No. 5, p. 172.

TABLE LXXXVI

Horizon.	Percentage in Air-Dry Soil.		pH		Titration Acidity.		T-S Value.
	Total Salt (%).	Soda (%).	In H₂O.	In n. KCl.	With n. KCl.	With Sodium Acetate.	
A	0·0-0·1	—	5·8	4·4	2·2	21·7	16·2
B₁	0·2-0·3	—	6·5	6·3	1·5	2·2	5·4
B₂	0·3-0·4	—	7·4	7·12	0·1	0·5	5·1
B₃	>0·4		7·6	7·21	0·1	0·3	4·9
C₁	0·25-0·30	0·14	8·5	7·88	0·15	0·15	4·8
C₂	0·20-0·25	0·17	8·7	7·16	0·10	0·20	4·7
C₃	0·20-0·25	0·20	8·9	7·79	0·15	0·15	4·5
D	0·20-0·25	0·09	8·9	7·42	0·17	0·20	6·5

TABLE LXXXVII

Depth of Horizon. in Cm.	Diameter of the Soil Particles (Mm.).								Ratio of Clay to Sands.
	3-1	1-0·5	0·5-0·25	0·25-0·05	0·05-0·01	0·01-0·005	0·005-0·0015	>0·0015	
A 0-20 } Profile	0·317	0·260	8·067	43·039	12·265	20·223	6·936	7·378	1:1·9
B₁ 20-37 } 50	0·052	0·064	4·425	39·169	9·917	18·228	11·715	15·825	1:1·2
A 0-18 } Profile	3·248	0·757	8·084	46·085	9·230	17·648	5·738	7·920	1:2·1
B₁ 40-66 } 54	1·282	0·457	6·155	47·455	7·534	12·022	8·500	15·867	1:1·8

strikingly in leached, alkali soils.* Alkali soils offer the best illustrations of the close connection between the physical properties of a soil and the chemical composition of the absorbing complex.

Morphological Characteristics.—The characteristic structure of this soil type is clearly connected with the physical and chemical properties. The surface horizon is usually crusty or foliated, due to deflocculation with water and the gradual settling of silt. This effect, however, does not penetrate to any great depth, as the soil does not easily take up water. Below the surface horizon we usually find the hard accumulation horizon (B), which may be divided into several sub-
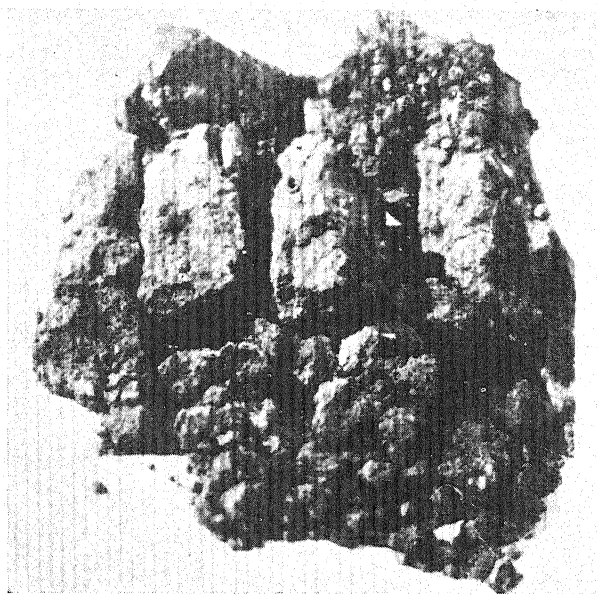
FIG. 29.

horizons. In the Hortobágy soil profile referred to above, we can distinguish the following three sub-horizons: B_1, the upper illuvial horizon, dark-brown in colour and with a well-developed columnar structure, 9-29 cm. in depth; B_2; middle illuvial horizon with prismatic structure, 29-55 cm. in depth; B_3, lower accumulation horizon, 55-70 cm. in depth, being a transition from the darker illuvial horizon with a structure to the light-yellow, loess-like, marly subsoil; it is free of carbonates. The columnar structure of a similar B_1 horizon is illustrated very strikingly by Fig. 29 (after a photograph by ARANY).

Below the B horizons we find the parent material (C), which is also divided into three horizons: C_1, loess-like marl rich in $CaCO_3$, 70-100 cm. in depth; C_2, accumulation horizon of $CaCO_3$, 100-125 cm.

* See SIGMOND, A. A. J. DE: "Hungarian Alkali Soils," etc., p. 78.

in depth; C_3, a horizon with a slightly rusty colour due to iron, and presumably resulting from the action of ground water.

Below the latter horizons we find the bluish-grey, impervious lake
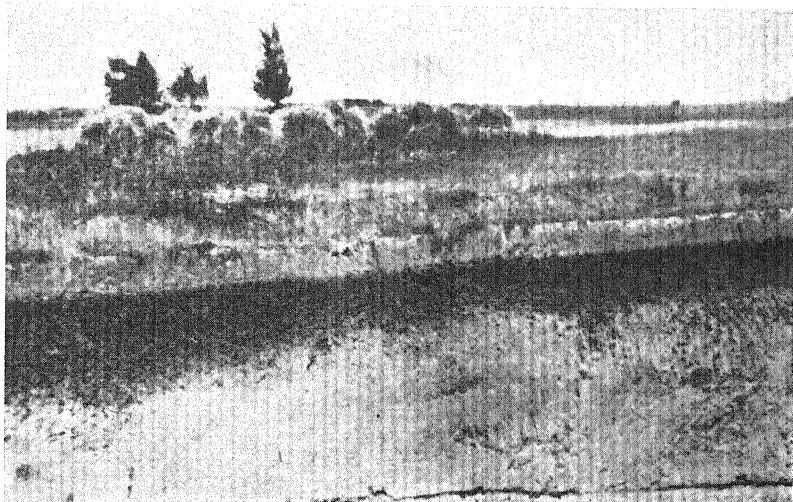
FIG. 30.
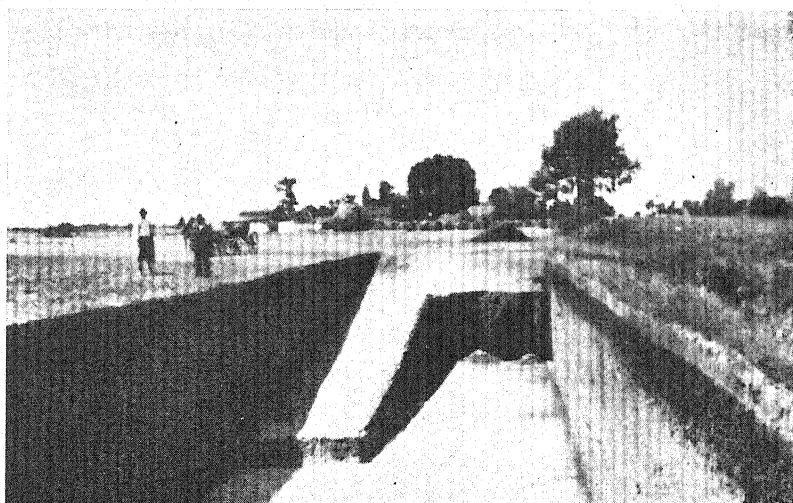
FIG. 31.

clay (D), characteristic of the heavy alkali soils of the Tisza Valley, and owing its colour to reduction processes. In many respects this horizon corresponds to the *gley* horizon of wet podsols and peat soils and is due to the swampy origin of Hungarian alkali soils.

Although the profiles of leached alkali soils (or " solonetz " soils) are not so highly developed in every case, the A, B and C horizons are usually distinguishable by their external characters (see coloured supplement, Profile 9).

Biological Characteristics.—Leached alkali soils are not as un-cultivable as saline soils, which bear only halophyte vegetation. *The natural vegetation of leached alkali soils is very xerophytic,* as the rapidity with which they dry prevents any but drought-resisting plants from surviving. Where attempts to cultivate these soils succeed, we may get a fair medium crop of wheat and barley. The quality of the former is good, of the latter poor. Owing to the difficulty of working the soil, yields are inclined to be rather uncertain.

These soils (known popularly as " fertile alkali soils ") may be successfully reclaimed by liming or by marling. A " fertile alkali soil " is shown in Fig. 30, while Fig. 31 shows a ditch for the supply of yellow marl (photos by DR. ARANY).

In the right-hand corner of Fig. 31 we get a very clear view of the darker accumulation horizon lying below the eluviation horizon.

Stage V. : Sub-Types of Leached Alkali Soils.

Russian soil scientists distinguish typical " solonetz " soils and " solonetz-like " soils, the latter having been formed from other soil types such as tshernosems or chestnut steppe soils. GLINKA describes the latter as occurring in the neighbourhood of " solonetz " soils, differing from them only in their " solonetz " formation being less well developed. He distinguishes " solonetz-like " and " slightly solonetz-like " soils.* We may, in addition, distinguish between " solonetz-like " soils formed from tshernosems, those formed from brown steppe soils and other brown soils, and those formed from other soils of a similar character. According to GLINKA it is in the brown steppe soil belt in particular that we find a very manifold complex of such soils. In these complex zones brown steppe soils are found alternating with " solonetz " soil, " solonetz-like " and " slightly solonetz-like " soils respectively.† On the strength of the data avail-able today it would indeed be difficult to determine the several stages of " solonetz "-formation, and I cannot separate from the " solonetz-like " sub-group the sub-group designated by GLINKA as " slightly solonetz-like." For the present, therefore, we can only distinguish two sub-types:

Sub-Type 1 : *Typical " Solonetz " Soils or Alkali Soils with Structure.*

Sub-Type 2 : *" Solonetz-like " Soils.*

* See GLINKA: *op. cit.,* p. 191.
† See GLINKA: *op. cit.,* p. 208.

Stage VI. : Local Varieties.

Local orographical conditions may result in producing very characteristic formations.

Local climatic and hydrographical conditions may also leave their impress on local varieties, the distribution of which is further influenced by the character of the soil zone or region. *Finally, the stage of development of the locality and its description may serve as a sure guide to the distribution of local varieties*, which in the case of leached alkali soils and other sodium soils may be very numerous.

Main-Type 4 : Degraded Alkali Soils (" Soloti " Soils).

Genetic Characteristics.—The leaching process which converts salty alkali soils into leached alkali (or " solonetz ") soils naturally is not restricted to the leaching down of water-soluble salts from the surface horizons, but continues by hydrolysing the Na of the complex. The Na is replaced gradually by H, which enters the complex in ever-increasing amounts, the result being that the originally alkaline reaction becomes an acid reaction, there being also other signs of acid leaching (*e.g.*, formation of iron concretions). For obvious reasons this process is most in evidence where for some cause there is a prevalence of more humid soil conditions favourable to eluviation.

Dynamic Characteristics.—The dynamics of both sodium and hydrogen soils operate jointly in the dynamic phenomena of these soils. Did the behaviour of these soils not resemble that of alkali soils so closely we might include them among the hydrogen soils—as we did with the degraded calcium soils. However, since the dispersing effect of absorbed Na cations is even greater than of H cations, these soils are dynamically more closely akin to the sodium than to the hydrogen soils.

Chemical Characteristics.—The essential difference as compared with the foregoing main type is that in the absorbing complex we find hydrogen penetrating at the cost of sodium. The reaction of the soil is acid.

Physical Characteristics.—These correspond almost entirely to those of the foregoing main type, though perhaps illuviation penetrates even deeper.

Morphological Characteristics.—The upper A horizon divides into two sub-horizons, the lower of which (A_2) shows the character of a podsol horizon. The columnar structure of the B_1 horizon is not so distinct as in the foregoing main type; it breaks up into nut-like clods. In the subsoil we often find iron-veined *gley* horizons, which mark the levels of the movement of the water table.

Biological Characteristics.—In the Russian " soloti " soils a few unpretentious trees and shrubs are found beside the steppe flora. The afforestation of Hungarian " soloti " promises to be successful; more-

over, these soils may easily be reclaimed by liming and may eventually be converted into normal calcium soils.

Stages V. and VI. cannot be described owing to lack of knowledge.

Main Type 5 : Regraded Salty Alkali Soils.

Genetic Characteristics.—According to VILENSKY* the first soils to form in Russia in the Post-Glacial period were saline soils. These were followed in a later, drier period by leached and degraded alkali soils, some of which, owing to a rise in the water table, are becoming saline again, thus having to a certain extent regraded.

Dynamic Characteristics.—We find the dynamics of the earlier conditions partly combined with those of the rising of salts.

Chemical Characteristics.—The chemical characteristics of the earlier conditions have been more or less obscured by the accumulation of water-soluble salts.

Physical and Morphological Characteristics.—The morphological features of the original alkali soil are made less distinct by the intrusion of salty solutions, but the characteristic structure is still discernible.

Biological Characteristics.—Biologically, these soils are in the worst possible condition, for the injuriousness of the high salt content of salty alkali soils is combined with the bad physical properties of leached alkali soils.

Stage V. : Sub-Types of Regraded Salty Alkali Soils.

At present we can distinguish only two sub-types:

Sub-Type 1 : *Salty Alkali Soils regraded from Leached Alkali (" Solonetz ") Soils.*

The absorbing complex is approximately saturated.

Sub-Type 2 : *Salty Alkali Soils regraded from Degraded Alkali (" Soloti ") Soils.*

The absorbing complex is largely unsaturated.

Stage VI. : Local Varieties.

The local types vary approximately according to the same principles as in the case of the other alkali soils.

Soil Order 13 : Brown Earths.

The term *brown earth* was introduced into soil science literature by RAMANN. His definition and characterisation were not very exact, and are still under discussion. We have already described several

* See VILENSKY, D. G.: 'Rep. I. Intern. Congr. Soil Scientists in Wash., 1927' (Kharkov, 1927), p. 120.

brown soils, some of which are closely akin to the brown earths described in this section, for they were formed under forest vegetation and do not betray any external signs of podsolisation, the acid leaching being revealed only by chemical analysis.   In his description of brown earths RAMANN points out that leaching is restricted to $CaCO_3$, while sesquioxides and silica are unaffected.   This RAMANN believes to be due to the humus formed in the soil not being acid but soon decomposing completely into CO_2 and H_2O, so that weathering takes place in a soil solution rich in carbonic acid.   The fact that in certain cases the surface horizon of brown earths is of a dirty brown colour, due to the humus content, does not contravene the principle which groups these soils among the soils undergoing carbonic-acid weathering; for the humus remaining in the soil is only what is called the inactive reserve which, the moment it becomes active, completely decomposes. As a consequence the mobilising effect of the acid humus on the sesquioxides cannot assert itself, or only to a very slight degree.   For that reason this soil order is rightly placed in my soil system at the head of the siallite soils poor in, or free of humus.   STEBUTT has also pointed out that the brown earth zone is a transition zone between that of the podsolic forest soils and the red earths.*

But brown soils are found not only among typical forest soils, but also among degraded tshernosems (see Sub-Type 2 of the latter main types).   Here, too, the characteristic feature is that at a certain stage of degradation the saturated humus decomposes and the iron oxide colours the soil brown.   According to STEBUTT this " rustiness " of the humus horizon—which is characteristic also of degraded steppe soils—is also a very frequent phenomenon in the case of brown earths. Brown steppe soils of various shades of colour have also been described, *but these soils owe their brown colour not so much to the Fe_2O_3 content as to the humus content, whereas in the brown earths their colour is due to the presence of iron hydroxide.*

Obviously, then, it is often difficult to differentiate between the various brown-coloured soils; and it is not surprising that the definition of brown earths has given rise to endless discussion.   In my opinion it is still a moot point whether STEBUTT's definition covers the term " brown earth " as first used by RAMANN.   From the point of view of soil systematics, however, it is irrelevant whether RAMANN's definition coincides with STEBUTT's or not; all we need know is that there are " brown earths " in which *both the sesquioxides and the silica are stable*, as has been shown by STEBUTT and LUNDBLAD, who, working by different methods, arrived at the same conclusions.   The only question of systematic importance is whether these soils should be called simply " brown earths," as suggested by RAMANN, or whether it would not be better to call them the brown variety of ferri-siallite or sialfer soils, applying the same terminology in the case of red and yellow soils.

* See STEBUTT, A.: " Lehrb. d. allg. Bodenkunde," pp. 439-41.

But, although according to RAMANN and other soil scientists brown earths occur in many places in Europe and North America, these soils have not been studied strictly enough according to the principles enunciated above. So the further distribution of brown earths by sub-types and local varieties must be left to future research.

There is, however, another type of brown-soil formation which agrees with that of brown earths in the rusty accumulation being at the top, so that the soil profile may be designated—like the brown-earth profile—by the letters BC. These brown soils are the result of erosion, which washes away the A horizon and thus prevents the formation of a normal ABC soil. There are also brown soils without any eluvial horizon; in these the brown horizon appears to be the residue of the illuvial horizon of some ABC soil which is otherwise approximately neutral and behaves like the brown earths described in the previous paragraphs. Brown soils of this kind I would call " secondary brown earths." It should be noted that the truncated forest soils included in the hydrogen soil order resemble the " secondary " brown earths in respect of formation, though they are decidedly acid.

Main Type 1 : Primary Brown Earths.

Genetic Characteristics.—Although opinions on the exact characterisation of true brown earths are extremely divergent and often contradictory, they nearly all agree on the external, and particularly the climatic, genetic factors—viz., that the zone of brown earths is virtually confined to the warmer regions of temperate humid climates, particularly where there is an alternation of very hot and dry, and very cold and wet seasons. RAMANN himself explained the lack of a humus cover as due to the leaf litter strewn over the ground the previous year decomposing entirely during the hot summer season and *preventing the formation of acid humus.** Almost the same climatological demarcation is to be found in the works of STREMME† and STEBUTT.‡ GLINKA includes the brown earths among the degraded steppe soils,§ though in my soil system these brown soils have been placed in the main type of degraded calcium soils. *The main type now under discussion includes only those brown soils in the formation of which acid humus plays no part.*

Dynamic Characteristics.—According to STEBUTT the dynamic system of the brown earths is not constant, but may easily turn in the direction of podsolisation or the formation of red earths. This may be seen in particular in the Balkans, where these three soil types

* See RAMANN, E.: " Bodenkunde " (1911), pp. 533 and 585.
† See STREMME, E.: " Die Braunerden " (BLANCK's " Handbuch," Vol. III., p. 160).
‡ See STEBUTT, A.: " Lehrb. d. allg. Bodenkunde," p. 439.
§ See GLINKA, K.: " Über d. sog. 'Braunerden ' " (" La Pédologie," Vol. XIII., 1911, pp. 17-48).

frequently adjoin. For podsolisation two things are necessary —
sufficient humidity and the formation of acid humus. The latter is
lacking in the case of brown earths, though a slight shifting of the
weather conditions may induce its formation and thereby lead to
podsolisation. The dynamics of red earths, on the contrary, depend
upon the rapid upward and downward movements of the sesquioxides
(in particular of Fe_2O_3), which require a warmer and periodically
drier climate than that which produces brown earths. A characteristic
feature of the dynamics of brown earths is that, though the silicates
decompose, the leaching of the bases prevents the formation of
zeolites, while the free sesquioxides and the silica gels remain in the
places of formation—the upper weathering layer—where they
accumulate.

This is illustrated most clearly in LUNDBLAD's three diagrams
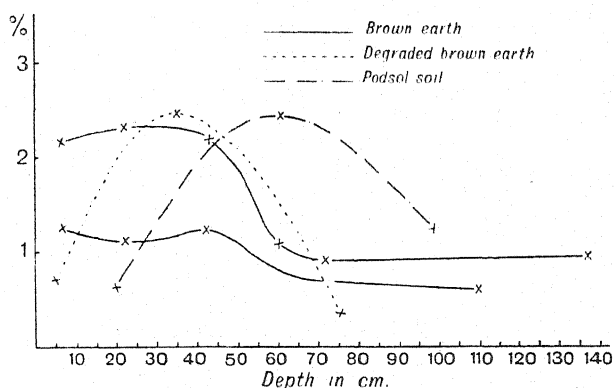
FIG. 32.

showing the inorganic colloids as determined by TAMM's method
(extraction with acidified NH_4 oxalate). Without entering into
details, Fig. 32 shows the quantitative changes of the total inorganic
colloids in the horizons at various depths in typical brown earths
(straight line), degraded or degenerate brown earths (broken line) and
typical podsol soils (dots and broken line) respectively.*

From the data of the above figure it appears that the gels originating
from the silicate weathering accumulate in the surface horizon—in
other words, remain in the place of formation. From an investigation
of Serbian brown earths STEBUTT comes to a similar conclusion,†
describing brown earths as soils in which the degree of silicate weather-
ing is high, whereas the washing down into lower layers of sesquioxides
and silica gels is only slight. No acid humus is formed, but the bases
are leached out one by one. At a certain depth the leached $CaCO_3$

* For details, *cf.* BLANCK's " Handbuch," Vol. III., pp. 165-7.
† See STEBUTT: *op. cit.*, p. 442.

accumulates (carbonated horizon). In this respect, therefore, these brown earths resemble degraded steppe soils. According to RAMANN another characteristic feature of brown earths is that, as the leaching is only of a limited character, the influence of the parent rock is able to assert itself.

Chemical Characteristics.—LUNDBLAD'S total chemical analyses show that there is slight podsolisation; for there is some accumulation of total SiO_2 in the surface horizon and of sesquioxides in the lower horizons, as may be seen from Table LXXXVIII.*

TABLE LXXXVIII

| | Mull (3-13 Cm.). | Brown Earth. | | The Same Values, calculated to Water- and Humus-Free Soil. | | |
| | | Upper Part (15-32Cm.). | Lower Part (100-115 Cm.). | | | |
	A	B	C	A	B	C
H$_2$O (hygroscopic)	1·66	1·00	0·52	—	—	—
H$_2$O (combined)	0·83	0·95	0·67	—	—	—
Humus	9·69	3·96	1·08	—	—	—
SiO$_2$	65·42	70·00	72·90	76·18	74·69	75·18
TiO$_2$	0·53	0·59	0·55	0·61	0·63	0·57
Al$_2$O$_3$	10·17	11·97	12·25	12·60	12·77	12·65
Fe$_2$O$_3$	2·51	3·31	3·18	2·88	3·53	3·28
CaO	1·58	1·41	1·84	1·82	1·51	1·90
MgO	0·09	0·12	0·15	0·10	0·13	0·16
K$_2$O	2·77	3·19	3·16	3·18	3·41	3·26
Na$_2$O	3·16	3·12	2·88	3·63	3·33	2·98

The fluctuations of some characteristic constituents soluble in hydrochloric acid are compared with the corresponding data for podsols in Table LXXXIX. (data supplied by STEBUTT).

It will be seen that, whereas the hydrochloric extract—apart from the lower carbonated horizon—does not change materially in the several horizons of brown earths, in the podsol profile we find a considerable accumulation, in particular of Al_2O_3 and Fe_2O_3, with depth.

Physical Characteristics.—These may vary considerably according to the character of the parent rock. In general, owing to the presence of the gels precipitated in the course of silicate weathering, the upper horizons show a tendency to form loam soils rich in iron.

Morphological Characteristics.—In view of the fact—stressed also by STEBUTT—that owing to the causes already explained the dynamics of brown earths are apt to vary considerably, and since the soils occur in temperate regions of the most divergent geographical situa-

* See BLANCK's " Handbuch," Vol. III., p. 168.

TABLE LXXXIX

Depth of Horizons.	Brown Earth.	Podsol.
	Soluble in 10 *Per Cent.* HCl.	
	Per Cent.	*Per Cent.*
0-15	20·87	16·51
15-30	—	14·85
30-45	20·12	23·11
70-90	22·79	27·02
105-120	36·03	—
	Fe_2O_3 *Per Cent. Soluble in* 10 *Per Cent.* HCl.	
0-15	2·40	3·47
15-30	—	4·29
30-45	3·04	6·01
70-90	3·84	6·57
105-120	2·56	—
	Al_2O_3 *Per Cent. Soluble in* 10 *Per Cent.* HCl.	
0-15	10·92	4·72
15-30	—	5·27
30-45	12·10	10·14
70-90	11·44	11·62
105-120	11·36	—
	Total CO_2 *Per Cent. of the Soil.*	
0-15	0·31	0·19
15-30	—	0·03
30-45	0·08	0·12
70-90	0·43	0·18
105-120	5·74	—

tion and of very different geological origin, the descriptions of profiles available in soil science literature also vary considerably. The confusion is aggravated by the fact that the term " brown earth " is not always used by scientists to describe the same type. We find descriptions of brown earth profiles, for instance, which mention a decided podsolic horizon,* though both RAMANN and STEBUTT categorically emphasise that the peculiarly characteristic feature of brown earths is that *they have no eluvial horizon, while the sesquioxides are*

* *Ibid.*

practically stationary.* Those brown soils in the profiles of which we find an eluvial horizon must therefore be excluded from this main type and included in another type of my system. The profile of a brown earth really belonging to the main type may be described as follows:

The surface horizon—usually marked as A—is more or less humous; but the humus is mild—so-called " mull " (excrements of earthworms), while the humus cover often found in forest soils is usually lacking, or where it does exist is barely 1-2 cm. thick. The colour of these soils is either dark or light dirty brown, according to the amount of organic matter; but in some cases we find also darker, greyish-black shades. The surface horizon is usually crumbly and finely granular, though the edges of the granules are straight, and are therefore unlike the tiny crumbs of typical tshernosems. With increase of depth the surface horizon becomes coarser and coarser in structure and poorer and poorer in humus, passing imperceptibly into the brown horizon proper, known as the B horizon. The structure of the latter is polygonal and much heavier than the surface horizon—a feature due to the absence of both humus and $CaCO_3$. At the depth at which $CaCO_3$ occurs, the soil becomes more crumbly and its structure looser. In the carbonated horizon the lime concretions often accumulate in layers, but where the parent rock was free of lime this horizon is naturally absent. Since the original parent material exercises a paramount influence on the development of the type, it goes without saying that morphologically also brown earths may vary widely. The essential thing, however, is that here *the surface horizon itself is* really *the accumulation horizon of soluble sesquioxides—i.e., the B horizon*—the upper part of which may be dirty brown (influence of humus) or even darker, but *does not represent a true eluvial horizon,* the result being that *we do not find any lower illuvial horizon either*. For that reason, in my opinion, these soils might be designated as *BC soils*, in which the B horizon may be divided into several sub-horizons (B_1, B_2, B_3). Since the nature of these soils is very powerfully influenced by the nature of the parent rock, it is advisable to indicate the latter in describing the subsoil (horizon C).† The deductions drawn by RAMANN from the experience and researches of years are very valuable, not only for determining brown earths, but also all young residual soils in which type characters are not yet fully developed. As in these cases the biological properties of the soil are also regulated by the nature of the parent rock, I shall deal with the effects due to the differences of parent material when discussing the biological characteristics.

Biological Characteristics.—Since the characteristic feature of the dynamics of brown earths is that the degree of leaching and accumulation is very slight, it is the mineral composition of the parent rock that determines the richness of the soil in plant food and also all other

* See RAMANN, E.: " Bodenkunde," p. 585; and STEBUTT, A.: *op. cit.*, p. 437.
† See RAMANN, E.: " Bodenkunde " (1911), pp. 587-600.

phenomena connected with its biological characteristics. RAMANN*
has summarised the influence of the parent material as follows:

(1) The main product of chemical weathering is a clay rich in iron.

(2) The composition of the soil may be determined from the nature
and weathering of the rock-forming minerals.

(3) Parent rocks rich in silicates generally do not weather so easily
as those poor in silicates.

(4) The lime content materially influences the chemical composition,
physical properties and humus content of the soil.   The humus content
is usually less in lime-rich than in lime-poor soils.

(5) The weathering of crystalline rocks may be materially modified
by the structure of the rocks.   In general those with coarse structures
weather most rapidly.

(6) In close regions or close geological formations the soils follow
the nature of the parent rocks.   In these cases the soil might justly
be called by the name of its parent material—e.g., sandstone or lime-
stone soils, etc.

(7) Weathering usually produces very characteristic forms on the
different rocks.   Granite and gneiss, for instance, generally form
rounded hillocks, eruptive rocks form cones and limestone plateaus
with precipitous escarpments.   We are therefore very often able to
guess the nature of the parent rocks and of the soils formed therefrom
from the shape of hills.

Since brown earths in the natural state are under forests—forming
in particular under deciduous forests—it is only natural that their
richness in plant food, combined with their physical structure and
their general water régime, is an important factor determining the
forest vegetation and indirectly also the development of the soil
itself.   Granite and gneiss soils, for instance, are according to RAMANN
so-called " medium soils," which favour the growth in particular of
conifers and possibly of beeches; they are rich in potash, fairly rich
in phosphoric acid, but usually poor in lime.   The organic material
decomposes quite quickly in warmer regions, though in cooler regions
it accumulates and may produce raw humus and podsolisation.   It is
well known that diabase soils are rich in plant foods and form clay
soils rich in iron, which are very suitable for the growth of valuable
trees.   The same is true of gabbro soils.   A peculiarity of trachite
soils—in particular of quartz-trachites (rhyolites) is that, whereas
the parent rock breaks up easily into coarse and fine sand, the chemical
weathering is a slow process, so that very little silt and clay are formed:
these soils dry easily and do not retain water.   On the other hand,
andesite, which is a quartz-free trachite, weathers quickly and produces
a soil of good physical quality.   Basalts weather fairly readily and
usually produce gravelly clay soils, while on mountain slopes very often
all that remains is a stony soil.   The surface of the stones weathers,

* See RAMANN: op. cit., pp. 386-7.

becoming yellow or reddish-brown.   This soil is usually rich in plant foods and, though gravelly, is favourable to the growth of more pretentious forest vegetation.

Pure limestones, on the other hand, produce forest soils of very poor quality, as they yield very little fine earth, but plenty of gravel, and water percolates rapidly through the cracks in the limestone, the soil above it consequently drying up.   What is left after the weathering of clayey limestones is usually a heavy clay soil, as the $CaCO_3$ is completely dissolved.   The limestone forming the subsoil behaves like a natural drainage system and soon drains off the surplus water. These soils are therefore suitable for the growth of deciduous trees but less suitable for conifers; and where for any reason the trees die out, the soil which in winter soon becomes wet and in summer dries up rapidly, favours even steppe vegetation.   In the case of sandstones the rapidity of the weathering and the quality of the resulting soil depend upon the nature of the binding material.   The quality of the soils formed from the various kinds of sands depends upon their mineral composition.

The above illustrations naturally apply only to cases in which the influence of the external soil-forming factors is as small as it is in the case of brown earths.   In the case of a typical podsol or tshernosem, on the other hand, the influence of the parent rock is quite subordinate.

Stage V. : Sub-Types of Primary Brown Earths.

From what has been said above we should conclude that it is best to group the brown earths according to parent rock.   Such a method would indeed seem suitable for differentiating local varieties.   For the present we can divide the brown earths into the following sub-types:

(1) *Sub-Type* 1.

Brown earth rich in humus, with a greyish-black surface horizon, but without eluvial horizon and with a lime-free subsoil.

(2) *Sub-Type* 2.

Brown earth, the surface layer of which is already brown or rather dirty brown, the subsoil being lime-free.

(3) *Sub-Type* 3.

Brown earth with carbonated subsoil.   The lime may be found as high as the lower parts of the B horizon.

Stage VI. : Local Varieties.

Here too—as explained above—*special attention should be given to the petrographic and general geological conditions.*

Main Type 2 : Secondary Brown Earths.

This soil type is really the truncated residue of erosion.   In principle this category might include all soils which originally contained a brown or dirty-brown accumulation horizon, but which, as the result of erosion or wind action, lost their A horizon and are approximately neutral.   Practically, they may be regarded chiefly as residues of former brown forest soils.   So far little has been done in the way of description or investigation of secondary brown earths, and I cannot discuss them in detail.   However, types of this kind do undoubtedly exist, and a place must be found for them in my soil system.   In their original condition they belonged rather to the order of hydrogen soils, but since in their B horizons brown forest soils are also approximately neutral, the soil left behind after the erosion of the acid A horizon behaves like the primary true brown earths.

Soil Order 14 : Red Earths.

The term " red earth " is as common as the popular appellation of the foregoing soil order; and before dealing with the main types of red earths I would like to define exactly the interpretation given in my soil system to that term.   BLANCK* describes many different theories relating to the " red earths " of the Mediterranean and then defines the formation of red earth as simply a phenomenon of colloidal chemistry, assuming that the mobile humus dissolves the iron-hydroxide gels, which are subsequently precipitated by lime in the form of red gels.   A *sine qua non* of the formation of these earths is therefore the formation of humus sols in the surface layer and the occurrence of lime in the subsoil only.   REIFENBERG, however, points out† that there is no need to assume a peptising effect of humus sols, as the silicic acid itself, which contains latent alkali and has still a slightly acid reaction, peptises the iron-hydroxide gels.   The iron oxide thus mobilised precipitates only in the presence of a higher electrolyte concentration, such as obtains during the migration upwards to the surface.   Thus, according to BLANCK's theory iron migrates downwards under the protection of humus sols, while according to REIFENBERG just the contrary happens, the iron precipitating during migration upwards.

STEBUTT,‡ availing himself of the data supplied by REIFENBERG'S investigations, regards the formation of red earths as a transition stage between that of brown earths and of laterites.   In his opinion the difference dynamically between the three soil orders is that, while

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* See BLANCK, E.: " Die Mediterran. Roterde (Terra Rossa)," in BLANCK'S " Handbuch d. Bodenlehre," Vol. III., pp. 199-230.

† See REIFENBERG, A.: Ztschr. Pflanz. Düng. Bodk., Part A, Vol. X. (1927-8), p. 183.

‡ See STEBUTT, A.: " Lehrbuch d. allg. Bodenkunde," p. 445.

in brown earths the end-products of silicate decomposition induced by carbonic-acid weathering are stable, in red earths and laterites the silicates decompose during the wet season and the decomposition products move downwards under the protection of silicic acid gels in a slightly alkaline medium and then in the dry season re-migrate upwards. Now, if a sufficient quantity of lime is present, it not only precipitates the SiO_2, Al_2O_3 and Fe_2O_3 complex gels, but also prevents the complexes breaking up into their constituent parts. According to STEBUTT, this is the genesis of red earths. In the case of laterites there is a lack of lime and in the constantly warm but alternately dry and wet periods the complex gels that have moved downwards always re-migrate upwards into the upper horizon, where, owing to the lack of lime and to the action of the high temperature and humidity, they break up into simpler gels; of the latter the Al_2O_3 and the Fe_2O_3 soon precipitate, while the more stable SiO_2 sols are washed down again, the upper horizon becoming gradually more and more allitic. Thus in the first phase of formation there is no difference between laterites and red earths; it is only in the second phase that they deviate from one another, the deviation being due primarily to the lime content of the red earths, though partly, also, to the effect of the wet and cold winter climate.

DEL VILLAR connects the formation of the red earth of Spain with that of rendzinas.* Endorsing REIFENBERG's theory of the migration of the SiO_2 and Fe_2O_3 complex colloids, he declares that the " terra rossa " is a direct derivative of rendzinas. Where the original forest vegetation is found—according to DEL VILLAR—we find a rendzina, whereas where the forest has been destroyed and the land subjected to cultivation, the humus layer gradually disappears and a typical red earth develops. STEBUTT also compares rendzinas and red earths,† and declares that while in the podsolic zone the presence of lime leads to the formation of rendzinas, in the laterite zone lime prevents the formation of laterites. On the other hand, in the Mediterranean zone—according to STEBUTT—a limestone bed produces a red earth, and a lime-free rock a podsolic soil.

Investigation of the rendzina and red-earth profiles studied by DEL VILLAR‡ shows that, chemically, both are typical calcium soils. Despite the studies made so far, we are not yet sufficiently familiar with all the factors contributing to the formation of red earth. Here too, as in the case of brown earths, the red colour of the soil has suggested the identification of soils of very different genetics and dynamics. The only infallible basis of differentiation from laterites is the ratio $SiO_2 : Al_2O_3$ in the hydrochloric extract, which in the case of laterites is less than 2:1. The other basis of differentiation referred to by STEBUTT—viz., that red earths are produced chiefly on limestone,

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* See DEL VILLAR, E. H.: " Les sols méditerranéens," etc. (1930), p. 210.
† See STEBUTT, A.: op. cit., p. 449.
‡ See DEL VILLAR: op. cit., pp. 152-63.

while laterites are formed out of lime-free rocks—is not always valid, because we know of red earths, too, which are lime-free. Another possible basis of differentiation between red earths and laterites is that the latter are very poor in bases, while the red earths are not so.

In view of all these points we must, when determining the various types of red earths, bear in mind that many questions still remain unanswered, the clarifying of which may modify the classification given below, and may possibly involve the differentiation of an entirely new type.

Main Type 1: Mediterranean Terra Rossa.

Genetic Characteristics.—The climate of the Mediterranean littoral might be described briefly as an alternation of a mild but humid winter and a constantly warm and dry summer period. This results in the soil solutions migrating downwards in the humid temperate period and to a certain extent leaching out the soil salts. $CaCO_3$ is also largely leached out; and during the humid season the sesquioxides undoubtedly, and the silicic acid and humus possibly, migrate downwards. According to BLANCK's theory, however, the moment the sesquioxides, etc., reach the lime horizon precipitation begins. This certainly cannot happen unless unsaturated humus is formed in the surface horizon, for otherwise the humus is stable and does not move in the profile. This may actually be the case in the regions investigated by BLANCK, but in the Spanish red earths, which DEL VILLAR declares to have been formed from rendzinas, the humus is saturated with calcium, so that the only possible explanation of the migration of iron seems to be that offered by REIFENBERG's theory. This theory enables us at the same time to explain the upward migration of Fe_2O_3 and SiO_2—in harmony with the idea expressed, for instance, by STEBUTT. According to that idea what is needed for the formation of both red earths and laterites is that wet periods should be followed by dry periods. Now this is the case with the Mediterranean climate. The alternation of wet and dry periods is necessary for the formation of red earths, in order that the decomposition products—in particular the Fe-Si dispersion—that sink to the lower horizons in the wet, warm season can migrate to the upper horizons during the dry summer and subsequently precipitate. The complex brought upwards and precipitated in the upper horizons does not decompose during the wet winter period—as it would, for instance, in the much warmer laterite zone—but remains stable, since the cooler temperature of winter does not encourage decomposition of the complex, while the Ca ions present in the soil prevent hydrolysis.* According to STEBUTT, therefore, Ca ions are needed for the formation of red earth, besides Mediterranean climatic conditions. DEL VILLAR's description and the analytical data of Spanish soils show clearly that where the parent rock was free of lime, under similar conditions, what he calls " xero-

* See STEBUTT: *op. cit.*, p. 451.

siallite " soils have been formed, which under our system must be included as a sub-type of the forest soil type.   This fact supports the hypothesis that *in the present Mediterranean climate red earths can be formed only from parent rocks rich in lime.*   However, certain results of investigation justify us in presuming that red earth not yet developed into a laterite may form also from lime-free parent rocks.   We shall deal with this question when discussing the main type Relict·Red Earths.

Dynamic Characteristics.—In addition to the energetic leaching out of the alkali salts the abundance of Ca cations in the soil prevents the decomposition of the Fe-Si dispersions and increases their stability. There is therefore an alternation of energetic leaching in the wet season and a rising of the soil solutions in the dry season, the red Fe-Si dispersions remaining in the upper horizons.

Chemical Characteristics.—In BLANCK's " Handbook "[*] and in the other works by him there are very many chemical analyses of red earths which do not, however, refer to the whole profile, but only to the red-earth horizons proper.   Consequently these analyses are not entirely satisfactory from the point of view of soil genetics and dynamics, for the data do not enable us to decide whether the accumulation of sesquioxides — particularly of Fe_2O_3 — is due to leaching downwards or infiltration upwards.

Table XC. shows the figures of the hydrochloric extract of the entire profiles of a few Spanish red earths.

Hc-2 is the profile of a red earth which owes its dark-red colour to the presence not only of ferric oxide, but also of a considerable quantity of organic matter; while Pa-7 and Va-3 are of a brighter red colour and contain less humus.   As we see, the ratio of $SiO_2 : Al_2O_3$ is in all cases greater than 2.

			Hc-2.	Pa-7.	Va-3.
Horizon I.	..	..	2·41	2·17	3·01
„ II.	..	..	2·76	3·70	3·09
„ III.	..	..	2·90	—	3·07
„ IV.	..	..	5·47	—	2·91

The above data show that these are not allites, though that does not mean that we may not find small quantities of free sesquioxides and also free SiO_2.   There are no signs of leaching down of Fe_2O_3, the maximum values being in the surface horizons.   However, not only the Fe_2O_3, but also the soluble Al_2O_3 and SiO_2, accumulate in the surface horizon, the data thus supporting STEBUTT's theory.   The total organic-matter contents and the pH values determined by DEL VILLAR are given in Table XCI.

Though not excessive, the quantity of organic matter present is fully sufficient to act as the source of the constant CO_2 suggested by STEBUTT's theory and therefore to promote the decomposition of

* See BLANCK, E.: " Handbuch d. Bodenlehre," Vol. III., pp. 233-46.

TABLE XC

	Hc-2.				Pa-7.		Va-3.				
	I	II	III	IV	I	II	I	II	III	III(b)	IV
Na$_2$O	0·17	0·26	0·19	0·09	0·31	0·13	0·29	0·18	0·23	0·09	0·21
K$_2$O	0·31	0·29	0·30	0·37	0·41	0·25	0·38	0·37	0·31	0·11	0·28
MgO	1·78	0·89	1·11	0·67	0·41	0·51	1·73	1·82	1·96	1·93	0·45
CaO	2·21	29·04	31·05	48·14	0·48	52·36	3·13	3·87	12·56	14·85	21·84
MnO	0·35	0·33	0·35	0·13	—	0·05	0·37	0·14	0·19	0·51	0·37
Fe$_2$O$_3$	3·02	1·95	1·85	1·12	1·91	0·48	3·51	2·05	2·62	2·34	1·95
Al$_2$O$_3$	7·87	3·60	2·16	0·26	5·18	0·25	4·57	6·86	6·14	6·79	5·41
SO$_3$	0·14	0·11	0·14	0·15	0·07	0·12	0·10	0·14	0·13	0·15	0·08
P$_2$O$_5$	0·02	0·03	0·02	0·008	0·02	0·004	0·025	0·028	0·03	0·03	0·02
CO$_2$	2·57	21·08	24·62	38·50	—	41·33	3·14	2·34	8·60	11·35	16·63
SiO$_2$	11·19	5·88	3·70	0·75	6·81	0·55	10·55	12·72	11·15	11·12	9·31
TiO$_2$	0·07	0·04	0·02	—	0·06	—	0·07	0·08	0·06	0·09	0·03
Insoluble residue	60·74	29·13	29·80	7·82	78·17	0·94	65·52	61·13	50·26	46·97	37·07
Loss on ignition	5·94	5·51	3·60	0·10	4·97	2·40	4·21	4·95	3·78	0·54	4·03
Moisture	2·95	2·13	1·39	1·84	1·94	0·15	2·37	2·92	2·45	2·41	2·02
Total	99·33	100·27	99·30	99·948	100·74	99·524	99·965	99·598	100·47	99·28	99·70

TABLE XCI

	He-2		Pa-7		Va-3	
	C×1.72 (%).	pH	C×1.72 (%).	pH	C×1.72 (%).	pH
I	2.55	7.2	2.03	7.0	1.31	7.15
II	1.53	7.2	—	7.3	1.12	7.15
III	0.51	7.3	—	—	0.62	7.15
IV	—	7.2	—	—	0.19	7.20

TABLE CXII

		S Value (Hissink).	U_p Degree of Unsaturation.	$T_p = S+U_p$	$V_p = \dfrac{S}{T_p} 100.$	Percentage of Exchangeable Cations calculated to $T_p = 100.$				
						Ca	Mg	K	Na	H
He-2	I	23.18	1.17	24.35	95.19	90.10	0.49	0.59	2.01	4.81
	II	15.45	0.46	15.91	97.11	91.51	4.80	0.31	0.50	2.89
	III	11.12	0.33	11.45	97.12	80.17	10.22	0.44	6.29	2.88
	IV	4.35	0.04	4.39	99.08	92.25	2.96	1.82	2.05	0.92
Va-3	I	17.27	1.97	19.24	89.75	80.92	3.17	2.96	2.70	10.25
	II	17.71	1.93	19.64	90.17	84.01	1.27	2.80	2.09	9.83
	III	15.31	1.72	17.03	89.90	82.79	1.76	1.64	3.70	10.10
	IV	14.48	1.39	15.87	91.25	81.98	4.54	1.57	3.15	8.75

silicates.   The humus is, however, saturated—a circumstance suggested
by the pH value being more than 7 and proved beyond a doubt by
the composition of the absorbing complex of Hc-2 and Va-3, as shown
by Table XCII.

From this table and from Table XCIII. (showing the composition
of the water extracts expressed in percentage equivalents) we see that
Ca is the predominant base and that the humus-zeolite complex must
be stable, as it is in rendzinas and tshernosems.

These data suggest that we should include the Spanish red earths
among the calcium soils, as DEL VILLAR actually does, and as we
have done with rendzinas.   From the same data it appears that
the chemical characteristics of the rendzinas and the Spanish red
earths coincide so closely that the only difference between these two
types is in the amount of organic matter, there being naturally much
more in rendzinas.   *It may be also that, while in colder climates rendzinas
in time are degraded into hydrogen soils, in warmer climates they change
into brown or red earths.*

Physical Characteristics.—A characteristic feature of red earths is
that they are in general heavy—indeed, exceptionally heavy—soils,
a circumstance explicable by the mere fact that the colloidal decom-
position products accumulate in the upper horizons.

Red earths in general show a high degree of hygroscopicity, a
phenomenon which explains other characteristic physical properties of
these soils.   We here give the data compiled by BLANCK and PINNER:*

		Hygroscopicity (determined by Mitscherlich's Method).
Abbazia: subsoil		16·3
Cigale		10·9
Montborron		11·1
St. Margerithe		13·6
St. Causian		17·2
Banjani (Montenegro)		16·08
Podgorica (Montenegro)		12·48

We can thus understand why, as LEININGEN† says, when a red
earth is thoroughly dried up, a slight rain has little effect on it.   Owing
to the high colloid content the soil's hygroscopic capacity is also high,
and plants are unable to take up hygroscopic water from the soil.
It is also owing to their high colloid content that red earths are im-
permeable.   Desiccated red earths shrink considerably and form deep
cracks, breaking up into irregular clods with a greasy and shiny surface,
probably caused by the surfaces of the soil particles being coated with
ferruginous colloids.

Morphological Characteristics.—Scientists differ as to what is the
true profile of red earth, for in very many cases red earths fill up

* See BLANCK's "Handbuch," Vol. III., p. 231.
† See LEININGEN, W.: Naturwiss. Z. Forst- u. Landwesen, 1918, No. 9.

TABLE XCIII

		Soluble in Water, calculated to 100 Grammes Dry Soil in mg.								Sum of mg. Equiv. of Cations	Percentage of Water-Soluble Cation Equivalents in Total Cation Equivalents.			
		CO_3	HCO_3	Cl	SO_4	CaO	MgO	K_2O	Na_2O		Ca	Mg	K	Na
Hc-2 {	I ..	—	46·6	2·1	5·2	24·1	0·8	2·9	8·1	1·22	70·5	3·3	4·9	21·3
	II ..	—	56·7	1·7	6·4	22·3	1·6	5·1	10·4	1·33	60·1	6·0	8·3	25·6
	III ..	—	40·9	7·1	17·6	27·4	1·0	5·9	10·6	1·49	65·9	3·3	8·0	22·8
	IV ..	—	39·0	2·8	8·7	14·3	1·8	3·6	14·7	1·15	44·3	7·8	7·0	40·9
Va-3 {	I ..	—	66·0	2·1	3·4	23·4	0·6	4·8	7·9	1·21	68·6	2·4	8·3	20·7
	II ..	—	59·7	4·3	4·6	26·4	0·6	3·4	10·6	1·38	68·2	2·1	5·1	24·6
	III ..	—	61·1	6·4	15·5	19·5	12·1	3·8	7·4	1·62	43·3	37·0	4·9	14·8
	IV ..	—	50·3	6·1	9·8	25·4	11·3	2·8	6·9	1·75	52·0	32·0	3·4	12·6

the hollows and clefts of limestone rocks and mountains, thus proving that they are not residuary soils. The full profile of the Spanish red earths discussed above may, however, be described as follows: upper horizon containing more or less humus, but in other respects similar to the red horizon below it. In most cases, however, in the soils commonly known as red earths there is no upper humus horizon, the red horizon coming to the surface. This latter horizon is, in respect of Fe_2O_3, an accumulation horizon and of illuvial origin, whether the iron is accumulated from below or from the eroded upper horizon; in any case it may be marked as B horizon. It usually rests immediately above the C horizon—the subsoil or raw parent rock itself. We may therefore call these soils BC soils—as we called the brown earths.

Biological Characteristics.—The luxuriant vegetation of the red earths found on the shores of the Adriatic, or on the Italian or French Riviera, proves that these soils, even though they frequently lack humus and nitrogen, cannot in general be described as poor. This is the opinion expressed by BLANCK on the basis of his investigations of the plant-food content of red earths, though he adds that certain red earths are poor in lime.*

Until we obtain more exact knowledge of the genetics and dynamics of red earths, it would be premature to attempt any subdivision of this main type. We shall therefore omit Stages V. and VI.

Main Type 2 : Relict Red Earths.

Genetic Characteristics.—The relict red earths of the Tokay district (Hungary) also resemble the Mediterranean " terra rossa " in external appearance. On the basis of BALLENEGGER's† investigations we may explain their formation as follows: the original red earth was formed in the Miocene Age out of rhyolite eruptions and their tuffs under climatic conditions resembling those of the Mediterranean zone today. It was later covered in many places by loess, subsequently carried away by erosion, the sticky and more durable " nyirok " remaining. This latter has been subjected during the present age to various changes. The present climate of North Hungary is very extreme, as it lies on the boundary between the dry and the wet regions.

Dynamic Characteristics.—These red earths were not formed under present-day climatic conditions and are absolutely lime-free. Without the protective influence of lime, in regions subjected to continuous humidity, they very soon show signs of eluviation. In hilly districts, where agriculture and viticulture are practised, the dry climate is able to assert itself, preserving both the red colour and the type of the soil.

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* See BLANCK's " Handbuch," Vol. III., p. 254.
† See BALLENEGGER, R.: Földtani Közlöny, Vol. XLVII. (1917), pp. 1 and 20.

Chemical Characteristics.—In Table XCIV. I give the total chemical analysis of the red " nyirok " soil of Mád in the Tokay district, of the clayey and sandy parts and of the rhyolite and the rhyolite tuff from which the soil has been formed.

TABLE XCIV

	Nyirok Soil.			*Rhyolite Tuff (Mád) (%).*	*Rhyolite Rock (Pálháza) (%).*
	Soil (%).	*Clay Fractions (%).*	*Sand and Silt Fractions (%).*		
SiO$_2$	63·87	48·13	74·88	70·19	75·29
Al$_2$O$_3$	14·78	20·41	10·93	11·86	13·42
Fe$_2$O$_3$	5·68	9·72	2·91	0·96	1·03
FeO	—	—	—	0·37	0·62
MgO	1·23	1·95	0·74	0·39	—
CaO	0·82	—	1·39	2·78	1·16
Na$_2$O	1·00	0·27	1·51	1·39	3·37
K$_2$O	2·31	2·54	2·15	3·58	3·65
Loss on ignition	4·29	7·67	1·95	5·72	1·25
H$_2$O (105° C.)	4·48	8·01	2·05	2·78	—
TiO$_2$	0·49	0·41	0·54	0·07	—
P$_2$O$_5$	0·08	0·10	0·07	0·03	—
MnO	0·07	0·02	0·10	0·04	—
Humus	0·98	1·31	0·77	—	—
Total	100·08	100·54	99·99	100·16	99·77

It will be seen that the chemical composition of the partially weathered soil fraction (column 4) is very similar to that of the rhyolite and rhyolite tuff.

The same result is given by the mineralogical analysis too. Moreover, the mineral particles of the sandy part of the soils are angular, fresh, without any trace of wear, showing that the " nyirok " soil is a residual soil formed from the rhyolite below it.

When we compare the chemical composition of the soil (column 2) with that of the rhyolite or the rhyolite tuff (columns 6 and 5 respectively), we are at once struck with the enormous decrease of silicic acid and the noteworthy increase of the sesquioxides. This is even more striking in the clayey part (column 3). It is clear, therefore, that silica has been leached out far more intensively than sesquioxides. It is possible, indeed, that the lack of lime in itself leads to silicate decomposition, and as the leaching is about the same as in laterisation,

the " nyirok " soils might possibly be regarded as relict soils of laterites and not of " terra rossa."

Physical Characteristics.—The " nyirok " soils are very heavy soils which are difficult to cultivate, as shown by the figures for the mechanical composition given in Table CXV.*

<div align="center">TABLE XCV</div>

Name and Depth of Soil (Cm.).		2·0-0·2 Mm.	0·2-0·02 Mm.	0·02-0·002 Mm.	<0·002 Mm.
Mád	0-15	2·3	31·1	25·7	40·9
	3-20	3·7	32·9	26·5	36·9
Magyarád ..	20-60	2·9	29·6	23·7	43·8
	60-100	3·6	33·6	25·3	37·5

The silt and clay combined amount to more than 60 per cent. of the soil, indicating that it is very highly dispersed.   In the Magyarád profile there are certain traces of mechanical illuviation (in the 20-60 cm. horizon).

The " nyirok " soils belong to the category of heavy clay soils; according to BALLENEGGER's data their plasticity values are as follows:

				Limit of Plasticity.		*Plasticity*
			Cm.	Upper.	Lower.	Number.
Mád ..	..	..	0-15	44·5	21·1	23·4
Magyarád ..	..	..	0-20	36·1	19·3	16·8

Morphological Characteristics.—As stated by BALLENEGGER, the profile of a " nyirok " soil varies according to the prevailing external circumstances.   Thus we find bare " nyirok " (BC soil), " nyirok " with humus cover (ABC soil), and " nyirok " with eluviation horizon— *i.e.*, degraded " nyirok " (A_1, A_2, BC soil).   Sometimes, also, " nyirok " soil is buried under loess.

Biological Characteristics.—" Nyirok " soils lack chiefly lime and humus.   In other respects they are excellent for viticulture.

We are not yet sufficiently familiar with the sub-types and local varieties to attempt their classification.

Soil Order 15 : Yellow Earths.

As soil science stands today, the term " yellow earth " is still very undefined, probably due to the fact (already mentioned) that the classification of soils by colour leads to the inclusion in one and the

* See BALLENEGGER, R.: " Magyarországi talajtipusok mechanikai vizsgálatának ismertetese " (Foldt. Int., 1915 Report), p. 12.

same category of soils differing in their nature, in their origin and in their dynamics. The indefiniteness is also due partly to our very deficient knowledge of the genetics and dynamics of the typical yellow earths. The name is supposed by some to have been derived from the yellow clay or loam of which the soil is largely composed. This soil order has been most exhaustively studied recently by HARRASSO-WITZ,* who divides the yellow earths into three groups, some being related to the siallites and others to the allites. As we have already seen, the red earths also constitute a kind of transition stage, so that in this respect the yellow earths run practically parallel to the red earths. We hear, also, of fossil or relict yellow earths. In many cases the humus cover of yellow earths has obviously fallen a victim to erosion, analogously to what happens in both brown and red earths. STEBUTT points out† that, as suggested by REIFENBERG's experiments, FeO in combination with silicic acid salts produces yellow solutions, and that the various hydrates of Fe_2O_3 all vary in colour, those containing less water being red, while the more hydrated oxides are yellow or brown. HARRASSOWITZ also points out that the yellow colour of the soil in the OSTWALD chromatic scale is sometimes not yellow, but vivid red (Kress No. 13), though to the eye it looks yellowish.

All these phenomena justify our describing yellow earths as a soil order related to the red and brown earths; and though we frequently find a humous horizon above the yellow layer, the character of the soil is not determined by the humus but by the yellow horizon.

The knowledge we possess does not justify our speaking of a definite type, still less of discussing the type characteristics. I shall therefore confine myself to summarising briefly the most important points known to us.

So far we have no real knowledge of the rôle played by the humus. According to GLINKA and RAMANN the yellow earths are generally poor in humus, but it would appear that in this respect the yellow earths resemble the brown and red earths; for as often as not the humus cover is entirely lacking. We cannot yet decide whether the absence of a humus cover is due to erosion, or indeed whether a humus cover is absolutely necessary for the development of yellow earths.

These earths are found in all kinds of climates. They are found as far north as Bavaria and the Black Forest, and they occur also in Southern Switzerland, in South France, in North and South Italy, and even in Java and Japan. Yellow earths are found, therefore, from the temperate zone to the sub-tropics and even the tropics themselves. According to HARRASSOWITZ the features common to them all are the migration of Fe_2O_3, Al_2O_3 and SiO_2, and the presence of a siallite complex. HARRASSOWITZ differentiates three stages:

(1) In those found in southern districts (near Lugano and in Graubünten, Switzerland) the $SiO_2 : Al_2O_3$ ratio is less than 2.

* See BLANCK's "Handbuch," Vol. III., pp. 182-93.
† See STEBUTT, A.: "Lehrb. d. allg. Bodenlehre," pp. 453-555.

(2) In those found in the northern districts (Bavaria and Baden) the $SiO_2 : Al_2O_3$ ratio ranges from 2 to 3.

(3) Where these earths have been formed from loess-like loam, the ratio is more than 3.

In general, however, we find in every case an intensive leaching of silica and bases, as compared with the parent material, and also an accumulation of sesquioxides. In this respect, therefore, the yellow earths resemble the red earths and differ from the podsolic formations.

For the detailed chemical composition the reader is referred to HARRASSOWITZ'S summary.* STEBUTT† also gives GEDROIZ'S data relating to the exchangeable bases and the free Al_2O_3 content of a yellow-earth profile from Java. These show that—apart from the surface humous layer—the Java yellow earth is highly allitic in character and therefore contains only very little exchangeable Ca and Mg.

Soil Order 16 : Pure Allites
(Main Type : Common Laterites).

Genetic Characteristics.—The term "laterite" was first used (1807) by BUCHANAN, who gave this name to the brick-coloured earth occurring in India suitable for making air-dried bricks.‡ Since then a very rich literature dealing with laterites has been produced, due not only to the extremely interesting character of these formations, but also to their being the most characteristic formations of the tropics. Here, too, *colour has failed to prove a trustworthy guide.* For, as we have seen, some red earths resemble laterites, while there are laterites which are not red. The red colour of laterites is due to their Fe_2O_3 content; but *the formation of laterites is characterised by the fact that during the weathering of the silicates the SiO_2 is almost entirely—in some cases completely—leached out, while the sesquioxides remain and sometimes are actually accumulated from elsewhere.* Where the parent rock contained, in addition to Al_2O_3, also iron compounds, the allitic soil formed takes on a red colour; but where there was originally scarcely any iron in the parent rock, the allitic soil formed is not red, but has a greyish colour resembling that of bauxite. Some scientists call these allitic soils "bauxite-laterites." We have placed these soils in Soil Order 18, including in Soil Orders 16 and 17 laterites which contain, besides Al_2O_3, sufficient Fe_2O_3 to colour the soil red.

Although there is not yet any unanimous opinion respecting the formation of laterites, scientists agree that *the essential thing about laterisation is that the Al_2O_3 contained in the original alumino-silicates separates entirely from the SiO_2, which is leached out, while the Al_2O_3*

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* See BLANCK'S "Handbuch," Vol. III., p. 191.

† See STEBUTT: *op. cit.*, p. 454.

‡ See BUCHANAN, H.: "Journey from Madras through Mysore, Canara and Malakar," Vol. II. (1807), p. 440.

remains as insoluble tri- or mono-hydrate.* The behaviour of Fe_2O_3 is much the same. HARRASSOWITZ, who in recent times has dealt most exhaustively with laterites, supposes allitic soil to be formed by laterisation not being confined to the upper horizons but, as a consequence of the excessive warmth and abundant rainfall of the tropics influencing the transformation of the parent rock to a considerable depth, extending in many places to 50-60 metres. In the upper horizons, as a result of the intense decomposition of silicates, the bases are first leached out almost entirely. But, as silicate weathering is in evidence even at depths of 50-60 metres, on their way downwards the soil solutions *rich in bases* dissolve more SiO_2 than sesquioxides. Hence, immediately above the parent rock there is formed an allitic layer which, while it retains the structure of the original minerals, is found to contain only sesquioxides unaccompanied by silicic acid. This zone—which in German is called *Zersatzzone* and in French *zone de départ* (LACROIX)—HARRASSOWITZ defines simply as *the residue of silicate weathering and leaching in an alkaline medium,* a definition supported by the fact that the quartz, which resists both weathering and leaching, also accumulates in this *zone of decomposition.* In the case of laterite formation, however, in the dry season following the wet season *the solutions migrate upwards,* forming an accumulation zone (*Fleckenzone*) *which contains considerably less quartz than the zone of decomposition.* In the case of laterites formed from granite, for instance, the only way to explain the small amount of total silicic acid (4·61 per cent.), determined by fusion, is that the amount of quartz originally present has been diluted by sesquioxides precipitated from the upward-moving solutions. In the profile from Ettakot (India) quoted by HARRASSOWITZ, only 0·43 per cent. quartz (SiO_2 insoluble in concentrated sulphuric acid) was found in the accumulation zone, whereas the proportion present in the allitic zone of decomposition was 26·10 per cent.† The fact that the quartz in the accumulation horizon apparently shows so considerable a decrease *denotes the accumulation of sesquioxides.* Sometimes we find above the accumulation zone an iron-ore zone, which in many cases is rich enough to be worth mining. Many designate the true laterite horizon merely as a leached-out residue. This is, however, not compatible with HARRASSOWITZ's theory, which coincides with the view expressed by STEBUTT—viz., that *the accumulation of sesquioxides derives from below and is not,* as GLINKA, GEDROIZ and others believe, simply a *residue of leaching down.* The only difference between the respective theories of STEBUTT and HARRASSOWITZ is that the latter *assumes that the small amount of unsaturated humus* formed transitionally under the forest vegetation of laterites *acts as a protective colloid* during the migration of the sesquioxides, whereas STEBUTT *attributes that rôle to the SiO_2-complex gels.* Both explanations are plausible, and only

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* See BLANCK's "Handbuch," Vol. III., pp. 395-7.

† *Ibid.,* p. 413.

future research will be able to decide which of the two is more correct.

As in the case of red earths, it is essential for the formation of laterites that there should be an alternation of dry and wet periods. What forms first is really a temporary siallite zone (in the so-called accumulation horizon) which later transforms into the surface lateritic zone. In other words, not all humid tropical soils or tropical red earths are laterites, which can be formed only where there is an alternation of dry and wet seasons. Sometimes those earths are only siallitic laterites or simply sands coated with an iron crust. The latter are really not autochthonous formations, but the residues of peaty or swampy waters—e.g., the iron ores of savannahs.

Dynamic Characteristics.—What has been said above makes it necessary to divide the dynamic phenomena prevailing in common laterites into two groups—the stages of leaching and of accumulation respectively. During the wet and hot season there is a prevalence of silicate weathering and of leaching down. This leads to an almost complete removal of bases generally and to so intensive a leaching of silica that the $SiO_2 : Al_2O_3$ sinks far below 2. In the dry periods, under the protection of the humus or SiO_2 sols, in a slightly acid medium (rich in CO_2) the sesquioxides migrate upwards and if they reach the surface precipitate and accumulate as a ferruginous crust. This accumulation may be on such a scale that all plants die off and the soil becomes transformed into a dead rock.

Chemical Characteristics.—For the chemical characterisation of laterites we must first determine the quantities of aluminium, iron, titanium, silicic acid and humidity, treating the hydrate water (by drying at a temperature of over $100°$ C.) as a separate item. In true laterites the other constituents are usually present in negligible quantities only; indeed, there is frequently a complete lack of alkalies and alkaline earths. The most characteristic feature is in any case the $SiO_2 : Al_2O_3$ ratio (Ki value) and the ba value,

$$\frac{CaO + Na_2O + K_2O}{Al_2O_3},$$

for these values determine the degree of lateritic leaching. In the above formulæ the quantities given are naturally not percentual but molecular.

American soil scientists—e.g., BENNETT*—give also the $SiO_2 : Al_2O_3 + Fe_2O_3$. This ratio HARRASSOWITZ designates as Sq; though from the point of view of characterisation he considers it superfluous, because the sesquioxides—with but few exceptions—as a rule move parallel during weathering and leaching. It is, however, very important to ascertain whether the ratios are obtained from the fusion analysis, or from the hydrochloric or sulphuric acid extract, or from the residue insoluble in sulphuric acid. For the Ki value of the fusion

* See STEBUTT: *op. cit.*, p. 454.

analysis may sometimes be misleading—in cases, namely, where we are not familiar with the composition of the parent rock. In the case of parent rocks containing quartz in particular the Ki value shown by fusion analysis may be misleading unless we deduct the SiO_2 not dissolved by concentrated sulphuric acid from the total SiO_2. The Ki value of the hydrochloric and sulphuric acid extracts (what VAN BEMMELEN calls the A and B complexes) show directly whether the weathered complexes are allitic or siallitic.

Today we have very many data available of analyses of laterites. I shall only give the figures relating to a laterite profile from India (after HARRASSOWITZ).* The analysis (Table XCVI.) is a remarkably complete one, as in addition to the data for the fusion analysis it gives the composition of the hydrochloric and sulphuric acid extracts and of the insoluble residue.

TABLE XCVI

LATERITE PROFILE FROM ETTAKOT (INDIA)

| | Gneiss. | Zone of Decomposition. | | | | Accumulation Zone Siallitic Allite. |
| | | Siallite. | | | Allitic-Siallite. | |
	A	B	C	D	E	F
Analysis by Fusion.						
SiO_2	64·76	69·47	47·62	58·60	52·80	14·13
TiO_2	0·57	0·31	2·20	0·77	0·54	2·27
Al_2O_3	18·85	18·11	18·25	25·23	28·37	36·85
Fe_2O_3	3·76	2·28	18·98	5·89	7·23	29·81
MgO	0·91	0·47	3·46	0·15	0·19	0·27
CaO	5·16	3·76	3·84	0·66	0·27	0·72
Na_2O	4·64	2·99	—	—	—	—
K_2O	1·55	1·08	—	—	—	—
H_2O+	0·31	2·08	6·49	9·20	10·76	16·43
H_2O-	(6·20)	(0·34)	(2·06)	(0·94)	(0·51)	(1·51)
Total	100·51	100·55	100·84	100·50	100·16	100·49
Analysis of the HCl Extract.						
Insoluble residue	88·35	86·95	55·11	67·48	70·20	19·08
Soluble SiO_2	2·57	3·35	8·92	6·47	5·58	7·25
TiO_2	0·27	0·18	0·77	0·35	0·11	0·46
Al_2O_3	5·67	5·15	13·70	9·42	6·72	31·31
Fe_2O_3	1·41	1·37	13·63	6·25	6·57	26·11
MgO	0·54	0·44	0·75	0·14	0·16	0·27
CaO	1·65	0·96	2·12	0·65	0·25	0·72

* See HARRASSOWITZ, in BLANCK's "Handbuch," Vol. III., p. 413.

Dissolved by conc. H_2SO_4 from the Insoluble Residue of HCl Extract.

SiO_2	..	..	5·49	0·82	15·32	30·77	21·12	6·97
TiO_2	..	..	—	—	1·42	0·42	0·43	1·77
Al_2O_3	..		—	—	3·99	15·31	32·21	5·55
Fe_2O_3	..		1·30	0·35	5·25	—	0·59	3·69
MgO	..		0·08	—	2·71	0·01	0·03	—
CaO	..		0·56	—	1·72	0·01	0·02	—

Analysis by Fusion of the Insoluble Residue of the conc. H_2SO_4 Treatment.

SiO_2	..	..	56·70	65·30	23·28	21·36	26·10	0·43
TiO_2	..	..	—	—	0·01	—	—	—
Al_2O_3	..		14·22	14·47	0·56	—	0·27	—
Fe_2O_3	..		1·05	0·56	0·10	—	0·06	—
MnO_3	..		0·29	0·16	—	—	—	—
CaO	..		3·76	2·80	—	—	—	—
Na_2O	..		4·22	2·73	—	—	—	—
K_2O	..		0·84	0·65	—	—	—	—
Ki \} by fusion K			5·80 —	6·50 1·10	4·40 0·76	3·90 0·67	3·20 0·55	0·65 0·11
Ki quartz-free			—	—	2·40	2·50	1·60	0·63
Ki $\{$ H_2SO_4 residue excluded $\}$			—	—	1·40	1·50	1·60	0·63
ba = B	..		1·00	0·72	0·39	0·048	0·017	0·036

These data may be compared with what has been said above respecting the chemical characteristics of laterites.*

Physical Characteristics.—Laterites in general are rich in colloids. According to Bennett† there is on the average 72·7 per cent. of colloids in the clayey tropical soils in Central America. True laterites are, however, *not plastic*, being easily friable in the dry state. This is attributable to the large quantities of hydrargillite (Al_2O_3 : $3H_2O$) in well-developed laterites, which reduces the plasticity of the colloids. Hence the more plastic a tropical red earth, the nearer it approaches to siallite and the greater the distance separating it from pure allites. Of the mechanical composition of laterites we may in general say that they possess a very fine dispersivity and, as the colloids are unsaturated, they are very inclined to disperse in water, while when dried they crack deeply.

Morphological Characteristics.—In a fully developed laterite profile we can distinguish four horizons: (1) the lowest horizon, composed of the original parent rock, frequently 50·60 metres below the surface; (2) on this, and formed from it, rests the horizon of decomposition, which in the present main type is allitic and contains Al_2O_3 in the form of a hydrate; (3) above (2)—but actually formed from it—lies the accumulation horizon, which is red loam and mottled as a result of

* For further details see Harrassowitz, *op. cit.*, pp. 401-35.
† See Bennett, E. R.: Soil Science, Vol. XXI (1926), pp. 349-74.

the accumulation of Al_2O_3 and Fe_2O_3; (4) finally, the surface iron horizon (crust) formed from (3) as an efflorescence, below which we not infrequently find an alumina-gel layer. In respect of formation, the surface horizon is analogous to the iron-concretion horizon of podsol soils, which we have designated as B_2. The accumulation horizon below it corresponds to the B_1 horizon—reversing the order of podsol soils. The decomposition horizon, which is a weathering residue, corresponds to the A_2 horizon of podsols, but is the result of an alkaline eluviation; its lower part—which differs but little from the original rock—may be described as the A_1 horizon. Below it lies the original rock (C). We may therefore describe the fully developed laterite profile with the following symbols: B_2, B_1, A_2, A_1, C, these symbols denoting also that the weathering begins from below and that the several horizons are leached both down *and up*.

Biological Characteristics.—The higher the development of a laterite, the less their suitability—owing to the intense leaching—for vegetation. The well-developed laterites are therefore bare, the density of the vegetation being in inverse proportion to the development of the iron crust. Laterites are frequently found bearing mighty primeval forests.

Stage V. : Sub-Types of Common Laterites.

HARRASSOWITZ has divided allitic laterites into three sub-types, which may be symbolised as follows:

(1) Fully developed allitic laterites, $B_2B_1A_2$ (A_1) C.
(2) B_1, A_2 (A_1) C.
(3) A_2 (A_1) C.

The last are mostly residues of erosion. Sub-type (2) is the most common.

Stage VI. : Local Varieties.

In the case of soils with such deep layers as laterites local circumstances may naturally produce a very large number of varieties.

Soil Order 17 : Siallitic Allites
(Main Type : Tropical Red Earths or Siallitic Allites).

In soil science literature these soils are usually treated under the same head as the common laterites, because in external appearance they very closely resemble pure allites. The essential difference between these soils and true, fully developed laterites is that the so-called decomposition horizon has not yet reached a degree of eluviation allowing us to class them as allites. They are only siallitic. It is true that this may be a stage of development of the previous main type; but, as we have seen more than once, in certain cases this stage of development represents a mobile equilibrium, which may last very

long and under certain circumstances may become to all appearances stabilised.

Chemically, HARRASSOWITZ fixed the line of division as follows: where the Ki value is 2 or more, the soil is a siallitic; where that value is less than 2, it is an allite. As we have seen, however, this method of distinction is very unreliable for fusion analyses, especially where the parent rock contains quartz. Now most laterites have only been analysed by fusion. HARRASSOWITZ, however, suggests another method of differentiation, based upon the total amount of sesquioxide hydrates, which may also be used for the purpose.* On this basis the amounts of free sesquioxide hydrates are as follows:

In pure allitic laterites	100-90 per cent.
In siallitic laterites	90-50 ,, ,,
In lateritic siallites	50-10 ,, ,,
In siallites	10 ,, ,,

These proportions may, of course, vary in the different horizons. Since the only criterion is whether the decomposition horizon is siallitic or not, I believe we should take as decisive the limit-value of the last group.

HARRASSOWITZ differentiates three further sub-types (Stage V.) on the basis of the degree of laterisation:†

(1) Accumulation horizon—red loam—decomposition horizon.
(2) Red loam—decomposition horizon.
(3) Decomposition horizon throughout.

In all three cases alike the decomposition horizon is siallitic.

Soil Order 18 : Allites Poor in Iron
(Main Type : Bauxite-Laterites).

We know very little of these soils. HARRASSOWITZ makes no mention of this variety of laterite as a separate soil order, though he notes that there are laterites in which the Fe_2O_3 content falls below 1-2 per cent.‡ In another place he points out that the laterites poor in iron are not red in colour, for which reason until recently these soils had not been recognised or had been wrongly determined.§ This circumstance may also be the reason why we are still not sufficiently familiar with this soil type to be able to describe it systematically. In theory, however, it may be assumed that laterites consisting chiefly of sesquioxide hydrates and therefore very similar to bauxite are formed from parent rocks originally poor in iron.

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* See BLANCK's "Handbuch," Vol. III., p. 400.   † *Ibid.*, p. 419.
‡ *Ibid.*, p. 392.   § *Ibid.*, p. 495.

Soil Order 19 : Soils of Mixed Rock Débris
(Main Type 1 : Hamada).

This is the term used in Chile for the soils of mixed rock débris covering a large part of the dry and hot desert; these soils are residual covers of the physically disintegrated parent rock. There can be no doubt, however, that the finer weathered particles have been swept away either by winds or by showers of rain. On the surface of the coarse débris and in its cracks we find traces of chemical decomposition too. These are therefore not real soils in the strict sense of the term; the forms of development are extremely primitive, though we occasionally find a scanty desert vegetation (cactuses).* In principle these soils are ectoadynamic.

Main Type 2 : Soils without Vegetation cracked by Ice.

To this main type belong both the soils absolutely devoid of vegetation formed on the bare rocky crust of the polar zones by the cracking action of ice and the residual débris formed on the bare surface of rocks above the snow line on high mountains. These are also devoid of vegetation. The German scientists call both these soils " Spalt-frostböden " (ice-cleft soils). In many respects they resemble the soils of the hot, dry deserts. They owe their formation to one and the same phenomenon, the only difference between them being that while in the case of polar soils the cracking is effected by the freezing of water, in the torrid zone the cause of the cracking is the alternation of excessive heat by day and excessive cold by night. These soils are also ectoadynamic.

Soil Order 20 : Soils of Mineral Grits.

We cannot yet speak of a definite type. The finer débris is found partly below the coarse hamada, though it occurs also on the surface. As yet it is a moot point whether these soils are the results of purely physical weathering or physical and chemical weathering combined (ectoadynamic soils).

Soil Order 21 : Soils of Fine Mineral Dust.

As in the case of the foregoing soils, here too we cannot yet speak of separate types, although in the hot desert soils of this kind are not infrequently found on the surface and may indeed form mounds (ectoadynamic soils).

* See BLANCK's " Handbuch," Vol. III., p. 461.

Soil Order 22: Desert Soils in which the Calcium of the Mineral Matter is Partly Mobilised.

Until quite recently it was believed that in desert climates, owing to the permanent and absolute character of the drought, there was not—and indeed could not be—any chemical weathering. However, the recent investigations of BLANCK, PASSARGE, KAISER and others have proved that this supposition is mistaken. Even in the dry deserts there is some rainfall; and, though that rainfall may be very small when distributed over the whole year, the fact that periodically very considerable quantities of rain fall, combined with the high temperature, makes the effect much more rapid and more energetic than if the same quantities of rain were to fall equably under colder climatic conditions. We have already indisputable data to prove that not only the easily soluble salts but also the silicates weather and their constituents become mobile. BLANCK and PASSARGE, for instance, have shown that a marl found in the Egyptian desert* contains concretions, particularly of gypsum. In all probability the gypsum originated from the parent rock, being used to cement the finer particles on the soil surface. It is interesting, however, that in the finer particles the SiO_2 has increased and the Al_2O_3 has decreased as compared with the parent rock. We may therefore assume a leaching of Al_2O_3—a process which I believe (the medium being calcareous) cannot have taken place except in the form of sulphates. This cannot of course be proved, as we have no exact data available.

Soil Order 23: Desert Soils in which the Silica of the Mineral Matter has been Partly Mobilised.

Here too we have very few reliable data available; but those which we do possess make it indubitable that in the case of the Egyptian soils formed from certain sandstones the finer weathered part contains far less SiO_2 than the coarser débris.† A similar regularity is observable also in the case of the Egyptian granite, pegmatite and gneiss soils.‡ The decrease of the SiO_2 is accompanied by a decrease in the amount of alkali salts, showing that weathering and leaching have taken place in an alkaline medium. This is probably one cause of the accumulation of Al_2O_3 and Fe_2O_3, as it was in the decomposition horizon of laterites.

Soil Order 24: Desert Soils with Easily Soluble Soil Crust.

One of the most frequent peculiarities of dry, hot deserts is the accumulation of various salts. These are either residual salts produced by the decomposition of rocks or have been washed down by desert

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* See BLANCK, E., and PASSARGE, S.: "Die chemische Verwitterung in der ägyptischen Wüste" (1925), p. 88.

† See BLANCK's "Handbuch," Vol. III., p. 456.   ‡ *Ibid.*, p. 458.

showers from more elevated places. As a consequence of the rapid evaporation of the water, the salts do not penetrate deep into the rock, but accumulate just below the surface, very often forming crusts. According to MORTENSEN* the composition of these salt crusts may vary considerably. The following positive constituents have been detected: Na, K, Ca, Mg and more or less Ba, Mn and Fe, and other metal cations in negligible quantities. Among the negative constituents we find Cl, SO_4, CO_3, PO_4, NO_3, Br, etc.

The variations, however, are not important enough from the standpoint of soil systematics to warrant our describing them here. In my opinion it is best to divide the salts into two groups determined by the measure of their solubility in water—viz., easily and slowly soluble salts. The easily soluble salts found most frequently in desert soils are NaCl, Na_2SO_4, Na_2CO_3 and $NaHCO_3$ and the double salt of the two last. The water-soluble salts of K and Mg are much rarer, as is also $CaCl_2$. In exceptional cases we find accumulations of $NaNO_3$. On the basis of their chemical composition only, the salt-crusted soils in the tropical zone constitute a kind of continuation of the sodium soils—i.e., of the salty alkali soils. They differ from the sodium soils in general, however, in being in a very primitive stage of chemical weathering, only the most easily formed and easily transported weathering products—the alkali salts—having accumulated in any considerable quantities, and even the origin of these salts is obscure. In any case, they originate from a larger weathering area than that in which they are found accumulated. The salt-crusted soils sometimes adjoin grey steppe soils. The grey and light-brown steppe soils are often called " semi-desert soils," as they constitute a transition between tshernosems and dark-brown steppe soils on the one hand and desert soils on the other. The desert soils are not yet sufficiently well known to enable us to attempt an exhaustive description.

Soil Order 25 : Desert Soils with Slowly Soluble Salt Crust.

These soils are also very little known. They usually contain the sulphates and carbonates of calcium. *Gypsum* and *anhydrite* accumulate in certain desert soils, but their origin is still wrapped in obscurity. They are usually accompanied by other salts (particularly sodium salts), very frequently only in the deeper layers. $CaCO_3$ occurs also in many places as a crust. All the soils belonging to this category are, however, undeveloped soils; and the salts may have originated from other places than those in which they are found accumulated. It is indubitable, however, that in even the dry deserts there is some soil weathering and that the most mobile products of this process—the water-soluble salts—often form characteristic salty products (*e.g.*, " salt pans," " salt efflorescences," " salt crusts," etc.) corresponding

* See MORTENSEN, H.: " Die Wüstenböden " (BLANCK'S " Handbuch," Vol. III., pp. 437-90).

with the prevailing seasonal water-flow and the orographical conditions. These surface formations, however, require a periodical accumulation of a greater amount of water.   Most frequently the rising ground water (seepage water) which contains the salts does not reach the surface, because it evaporates rapidly.   The salt left behind loosely cements the raw material of the soil, but does not accumulate on the surface as easily as in the less dry deserts.

From the pedological point of view the salt-crusted desert soils— like the other desert soils—can only be regarded as very primitive soil formations.   I should mention in this connection that on the surfaces of certain rocks in deserts we often find so-called " protective coatings " (" Schutzrinden ").   Though they are the surface products of the chemical decomposition of rocks, these formations cannot be regarded as soils.*

CHAPTER XV

PHYSICAL AND PHYSIOLOGICAL CLASSIFICATION OF LOCAL VARIETIES (STAGES VII. AND VIII.)

Stage VI. of our soil system—local varieties of types—affords an opportunity for a general pedological characterisation of the several occurrences; nevertheless, for an adequate physiological characterisation local soils must be classified more exhaustively both physically and with regard to their plant food reserves.   This is rendered essential by practical considerations.   In former times, when soils were studied for practical (agricultural, forestry, horticultural, etc.) purposes, their study and classification were confined exclusively to physical and nutrient properties.   This method might be spoken of as practical classification, although today practical soil classification, which determines first, second and third quality soils, etc., for land assessment, is in general effected solely on the basis of economic valuation.   It was the Russian soil scientists who first—even prior to the Great War— employed the scientific determination of soil properties as the basis of soil evaluation.   For instance, it was of the greatest importance to determine whether the soil of an estate was a tshernosem, podsol, etc., for this fixed the permanent character and practical value of the soil.   Tshernosems are generally rich and remain rich, whereas the podsols are leached out and stand in need of constant replenishment and require hard work.   Of great interest are STEBUTT's observations respecting the dynamical conditions and changes of soils in relation to fertilisation, etc.,† as they illustrate the spirit underlying the land

* For details see LINCK, G.: " Schutzrinden " (BLANCK's " Handbuch," Vol. III., pp. 490-505).

† See STEBUTT, A.: " Lehrbuch," etc., pp. 460-99.

evaluation of the Russian scientists. The Bureau of Soils of the
U.S.A. divides soils first into " series " named after the places where
they were first found, subsequently classifying soils of a similar type
on the basis of their mechanical composition. The fact that the
practical-minded Americans have found it insufficient to ascertain
the mechanical composition (texture) of soils, but have found it neces-
sary also to establish certain practical types (called " series "), shows
that the physical or even physiological study of a soil is insufficient
even from a practical standpoint, for soils possess certain local charac-
ters which determine the *type* of clay, loam, loamy sand, sand, etc.
The soil series of the Bureau of Soils correspond in practice to the local
varieties of our soil system, the only difference being in the mode of
characterisation and in the evaluation. For instance, if the character-
istic data of the American soil series enabled us to determine—as
MARBUT has done in his " Atlas of American Agriculture "—the
character of the type of these series, the whole American system of
soil classification might very easily be embodied in my soil system.
Such a procedure would be of importance both scientifically and from
a practical point of view, for the classification would then also give
an idea of the dynamics of the soils of the various series. The practical
advantages accruing therefrom to agriculture cannot yet be adequately
gauged. This point I propose to illustrate by a few examples from
my own experience of Hungarian soils.

In many parts of the Hungarian lowlands we find immediately
adjoining (*a*) tshernosems (calcium soils), (*b*) so-called " szik " soils
(leached or degraded alkali soils), and (*c*) so-called " black meadow
clay " soils, which are probably degraded calcium soils which in any
case belong to the hydrogen soil order. It often happens that all
three soils have been formed from loess and are clayey. Sometimes
we find that there are no material differences in their texture either.
Nevertheless, the behaviour of the three soils under cultivation is
never the same. The calcium soils are the easiest to work and do not
require special attention. The black meadow clay soil, however—
although it may also have originally been a calcium soil—in its later
swampy condition took up hydrogen (in its absorbing complex), so that
when dried it shrinks and becomes very hard, while under cultivation
it breaks up into coarse boulders with even surfaces. The cultivation
of the " szik " soil—the third in order—requires special attention
and causes much trouble. When dry it is hard as flint, while in the
wet state it deflocculates and is usually sticky. It is difficult to find the
proper condition when the humidity of the soil is best for cultivation.

Let us assume that by suitable cultivation all three soils have been
put in the best condition. What will happen after a heavy rainfall ?
The " szik " soil deflocculates entirely and the effects of the extremely
difficult cultivation are nullified, while the soil after drying again may
become so encrusted as to prevent sowing and even to reduce the sprout-
ing of seed already sown. The whole work has therefore to be begun

afresh. The black meadow clay soil does not possess such bad qualities, though it, too, shows a tendency towards silting, so that it needs more careful and more frequent loosening than the tshernosem. Of the three the tshernosem is most easily put into a good physical condition— *i.e.*, given a crumb structure, which it retains after heavy rainfall.

The above example shows what striking differences there may be between the soils of various orders and types occurring in one and the same district, even though the mechanical composition and physical properties of the soils may be identical. It is quite natural that these differences exercise a far-reaching effect—both quantitatively and qualitatively—on the development of cultivated plants.

The physiological and chemical conditions of the soil also depend upon the character of the soil type. Tshernosems are usually rich, not only in plant-food reserve, but also in readily soluble plant foods accessible to plants. To this must be added the peculiarity of these soils, so valuable from a practical standpoint, that the plant food once dissolved is not leached out, and in the event of its not being taken up by plants is absorbed by the soil. Virgin tshernosems, when under cultivation, can dispense with all fertilisation for a considerable time. Their only natural defect is a lack of humidity, which is very often the limiting factor controlling the quantity and quality of the yield. With varying local conditions the degree to which the plant foods are leached out also varies. Today it is common knowledge that tshernosems are usually richer in easily soluble phosphoric acid, for instance, than the acid forest soils. But let us assume that the phosphoric acid soluble in dilute nitric acid is approximately the same in both. It may then happen that phosphoric fertilisers will have no effect on the forest soils, though very efficacious on the tshernosems. This may be due partly to the acid forest being poor in other nutrients too, so that even the small available reserve of phosphoric acid is sufficient. Tshernosems, however, are rich in other plant foods, so that the reserve of phosphoric acid, even if as large as in the forest soil, is nevertheless relatively small as compared with those of the other nutrients. There may, however, be another difference between the respective phosphoric acid reserves of the two soil types. I have already pointed out that plants, in addition to receiving food from the soil solutions, dissolve plant food themselves. This is particularly important in the case of tshernosems, where there is usually sufficient finely dispersed lime present not only to protect the soluble phosphoric acid against leaching out, but also to impede its absorption by plants.

The object of the above illustration was to show that for the physiological characterisation of a soil—viz., in respect of plant-food reserve conditions—it is necessary that we should be fully familiar, both scientifically and practically, with the soil type.

These remarks are essential to illustrate adequately the close connection with my whole soil system of the two last stages now to be discussed.

Stage VII. : Physical Classification of Local Varieties.

Since the days of ATTERBERG, who classified soils on the basis of their physical properties and their mechanical composition, soil scientists, though they have studied physical properties and mechanical composition thoroughly enough, have failed to make use of the advantages of ATTERBERG's system of physical classification or to elaborate a better one.

From the physical point of view we may distinguish three great groups of soils—viz., loose (*sand*), heavy but not plastic (*loam*), and plastic soils (*clay*). I refrain from mentioning gravel and rocky soils, because their physical composition is so completely dominated by the gravel or boulders that the behaviour of the other constituents hardly counts at all. It is extremely simple to distinguish the three main groups: sand in the dry state does not cohere, and breaks up into its elements at the slightest pressure; the loam and clay soils cohere when wet and form clods of varying hardness when dry, a fact easy to test by crushing the crumbs in our hands. It is also easy to ascertain whether a coherent soil is plastic or not. If the soil is wet enough in the natural state, we can try to roll it into thin wire. If the soil is plastic, we get thin, wire-like threads; but if the soil is not plastic the threads break and crumble while being rolled. By these simple methods we may therefore divide local varieties into three physical main groups. There is of course need of further classification; and as the basis of such classification we may in principle accept that suggested by ATTERBERG. For the physical characterisation of soils *the water régime* is a property of extreme importance from both the practical and the pedological point of view. It is particularly important to ascertain the amount of available water which the soil is able to store and the depth of the roots. Since for reasons already given I have not dealt exhaustively with the physical characteristics of soils, I cannot here discuss more closely the basic principles of a physical classification. In my system of classification the essential point is that Stage VII. shall deal with the physical characterisation and the grouping of local varieties.

Stage VIII. : Classification of Soils according to Plant-Food Reserve.

In the chapter dealing with the plant-food reserves of soils I showed that the quantities, solubility and availability of the various plant foods *represent only a temporary cross-section of the dynamic system of a soil*. Consequently, where we are not familiar with the whole dynamics of a soil, we cannot possibly decide to what extent the determined nutrient content may be taken as a criterion of the actual plant-food conditions. The dynamic character of a soil is best shown by the soil type. In the eighth stage of my system, therefore, all we have to ascertain is the actual plant-food conditions

present in the different local varieties. In many cases the total quantity of plant food suffices—*e.g.*, in the humid tropical climate weathering and leaching are so active that even the fresh minerals and the organic nitrogen are readily transformed into available plant food. In our temperate climate, however, the total amount of plant food usually informs us only of the soil's ultimate richness, and account must also be taken of the easily soluble or available nutrients which afford the vegetation the necessary nutrition. From the standpoint of practical agriculture there are four plant foods to be taken into consideration—N, P, K and Ca. As regards the latter the mere determination of the soil type gives us some qualitative information, and it is only where there is a shortage of Ca that the amount required must be determined.

A shortage or abundance of nitrogen, phosphoric acid and potassium nutrients, on the other hand, does not materially affect the general dynamic character of the soil. Tshernosems, for instance, which are usually rich in plant foods, may yet be deficient in phosphoric acid reserve. This does not affect their tshernosem character, but where a steppe soil, for some reason or other, loses so much of its calcium as to need liming, it loses its steppe-soil character and becomes a degraded calcium soil.

It follows, therefore, that in Stage VIII. of my system it suffices to determine the plant-food conditions in respect of N, P_2O_5 and K_2O, and on that basis to distinguish *rich* soils (soils not requiring fertilisers) and soils *poor* in certain nutrients (soils on which artificial fertilisers may be successfully employed). The determination of the above conditions may be effected in various ways, and may extend also to measuring nutrient deficiencies. As in the case of the foregoing Stage, here, too, many comparative experiments will be necessary to find internationally acceptable methods suited to different soil types, and thereby supply the deficiencies of this Stage of my system. However, a suitable place had to be found in my system for the plant-food conditions of soils, as they are important not only from an agricultural point of view, but also scientifically; for *the soil is the natural source and store of plant foods*.

Tables XCVII.-CIII. on the following pages give a summarised survey of my General Soil System on the basis of the foregoing chapters.

TABLE XCVII

1. ORGANIC SOILS

I. Main group		
II. Sub-groups	1. Raw organic soils (turfy soils)	2. Humified organic soils (peat soils)
III. Order	1. Turfy soils poor in bases 2. Turfy soils rich in bases without salts 3. Saline turfy soils → Further classification uncertain	4. Acid peat soils 5. Neutral peat soils 6. Saline peat soils → Further classification uncertain
IV. Main type	1. Turfy soils formed from different mosses	1. Acid "High Moor" 2. Neutral "Low Moor" → Further classification uncertain
V. Sub-type	1. *Sphagnum* turf 2. *Eriophorum* turf 3. *Scirpus* turf 4. Moss turf with *Calluna*, etc. 5. *Sphagnum* with lichens 6. *Sphagnum* with *Scirpus*	1. Herbaceous hydrophyte turf 2. The same with mosses 3. The same with *Calluna*, etc. 4. The same with forest vegetation

VI. Local Varieties: (1) Local orography; (2) local morphological conditions; (3) hydrological conditions; (4) botanical determination of the turfy layers, their depths and the quality of the bottom layer; (5) the rate of decomposition; (6) cultivation.

VII. Physical classification: (1) Main physical characteristics; (2) mechanical analysis; (3) water régime.

VIII. Physiological classification: Total and easily soluble P_2O_5, K_2O and total N.

TABLE XCVIII

I. Main group	2. ORGANIC MINERAL SOILS		
II. Sub-group	3. Raw organic mineral soils		
III. Order	7. Endoadynamic soils	8. Ectoadynamic soils	9. Pseudoadynamic soils.
IV. Main type	1. Skeletal soils	1. Structural soils of the Arctic — 2. Polygonal soils — 3. Tundra soils — 4. Skeleton soils of high mountainous regions	1. Recent alluvial soils — 2. Littoral soils
V. Sub-type	1. Sedentary detrital soils — 2. Colluvial detrital soils — 3. Skeletal soils, deposited by water — 4. Skeletal soils, deposited by wind	1. Garland-like stone soils* — 2. Net-like stone soils* — 3. Earthy islands* — 4. Striated stone soils* — (Polygonal) 1. In the Arctic — 2. In tropical deserts — 3. Saline polygonal soils — (Tundra) Further classification uncertain	1. In the upper part of the river — 2. In the middle part of the river — 3. In the lower part of the river — 1. Littoral sand dunes — 2. Marsh soils—*i.e.*, littoral salty soils

VI. Local varieties: (1) Classified and characterised according to (1) orographical; (2) local climatic or meteorological; (3) hydrological conditions; (4) parent rock; (5) degree of development of the soil profile.

VII. Physical classification of the local types: According to (1) the main physical characteristics; (2) the mechanical composition (soil texture); (3) the water régime of the soils.

VIII. Physiological classification of the local types: According to content of total and slightly soluble or available N, P_2O_5 and K_2O.

* Detailed description in MEINARDUS, W.: "Arktische Böden," BLANCK's "Handbuch der Bodenlehre," Vol. III., pp. 82-96.

TABLE XCIX

I. Main group

II. Sub-group

2. ORGANIC MINERAL SOILS

III. Order

4. Humic siallite soils

10. Hydrogen soils

IV. Main types

1. Turfy mineral soils	2. Wet grassland soils	3. Ordinary forest soils	4. Truncated forest soils	5. Degraded calcium soils
1. A horizon turfy, *gley* horizon (G) in the subsoil	1. A_1, A_2, B, C, G A_1, A_2, B-G, C, G	1. A_2 horizon strongly podsolised	At present unknown	1. Slightly degraded Ca soils
2. A horizon moory, *gley* horizon in the subsoil	3. A_1, A_2, G	2. The same as 1, with iron-ore horizon		2. Dark-grey or brown, slightly degraded Ca soils
3. A horizon muddy, *gley* horizon in the subsoil		3. Similar to 1, with a B_1 horizon rich in humus		3. Light-grey, well-podsolised degraded Ca soils
4. A_1 horizon turfy, A_2 horizon podsolic, subsoil with or without *gley*		4. Similar to 3, with iron-ore horizon		4. Ca soils degraded by high levels of ground water
5. Similar to 4, but A_1 horizon moory		5. A_2 horizon not developed, but visible difference between A and B		5. Degraded rendzina soils
6. Similar to 5, but A_1 horizon muddy		6. A and B not visible, only determined by chemical analysis		
7. A horizon turfy, no podsolic or *gley* horizon				
8. Similar to 7, but A horizon moory				
9. Similar to 7, but A horizon muddy				

V. Sub-types

Categories VI, VII, and VIII, are built up as in Table XCVIII.

TABLE C

I. Main group
: 2. ORGANIC MINERAL SOILS

II. Sub-group
: 4. Humic siallite soils

III. Order
: 11. Calcium soils

IV. Main types
: 1. Tshernosems | 2. Prairie soils | 3. Rendzinas | 4. Black soils of sub-tropics and tropics | 5. Brown "steppe" soils | 6. Grey "steppe" soils | 7. Secondary and tertiary Ca soils | 8. Calvero soils

V. Sub-types:

1. Tshernosems

1. $\dfrac{A}{C}$ $\dfrac{A_1}{A_2\,Ca}$

2. $\dfrac{A_1}{A_2\,Ca}\Big/C$

3. $\dfrac{A_1}{A_2\,Ca}\Big/C_1$ 4. $\dfrac{A_1}{A_2\,Ca}\Big/C_1\,Ca$

5. $\dfrac{A_1}{A_2\,Ca}\Big/C\,Ca$ 6. $\dfrac{A_1}{A_2}\Big/C\,Ca$

7. $\dfrac{C_1\,Ca}{C_2\,Ca\,Na}$ 8. $\dfrac{A\,Ca}{C\,Ca\,Na}$

$\dfrac{A\,Ca}{C\,Ca}$

9. Tshernosem on sand
10. Tshernosem on hard rocks

2. Prairie soils — Uncertain

3. Rendzinas

A. On carbonate sub-soil
 1. Marl
 2. Limestone
 3. Marble
 4. Dolomite
B. On sulphates
 1. Gypsum

4. Black soils of sub-tropics and tropics — Uncertain

5. Brown "steppe" soils
 1. Chestnut-brown soils
 2. Light-brown soils

6. Grey "steppe" soils — Uncertain

7. Secondary and tertiary Ca soils
 1. Tertiary Ca soils
 2. Artificial Ca soils made from moor soils
 3. Artificial Ca soils made from acid soils
 4. Artificial Ca soils made from alkali soils

8. Calvero soils — Uncertain

Categories VI, VII, and VIII, built up as in Table XCVIII.

TABLE CI

Category					
I. Main group	2. Organic Mineral Soils				
II. Sub-group	4. Humic siallite soils				
III. Order	12. Sodium soils				
IV. Main type	1. Saline soils	2. Saline alkali soils	3. Alkali soils poor in alkali salts	4. Degraded alkali soils	5. Regraded soils → Regraded saline alkali
V. Sub-type	1. With sulphates 2. With chlorides 3. With sulphates and chlorides 4. With sulphates and carbonates 5. With chlorides and carbonates 6. With chlorides, sulphates and carbonates 7. Soda soils	Similar sub-groups as in main type I	1. "Solonetz" soils 2. "Solonetz-like" soils	Further classification not yet established	1. Regraded from "solonetz" 2. Regraded from degraded alkali soils
VI. Local varieties	1. Further classification according to the nature and quantity of salts		1. Further classification according to the depth of the accumulation horizons of CaSO$_4$, CaCO$_3$ or sodium salts		1. Further classification according to the nature and quantity of alkali salts

Further classification according to (2) local orographical; (3) climatic; (4) hydrological conditions; (5) the nature of the parent rock; (6) the local development of the whole profile.

Categories VII. and VIII. similar to Table XCVIII.

TABLE CII

2. ORGANIC MINERAL SOILS

I Main group						
II. Sub-group	Ferric siallites			6. Allites		
III. Order	13. Brown earth	14. Red earth	15. Yellow earth	16. Pure allites	17. Siallitic allites	18. Allites poor in Fe_2O_3
IV. Main type	1. Primary 2. Secondary	1. Mediterranean "terra rossa" 2. Relict red earth	Further classification not yet established	1. Normal laterite	1. Siallitic laterite	1. Bauxitic laterite
V. Sub-type	1. Brown earth with a humiferous cover, subsoil free of $CaCO_3$ 2. Pure brown earth, subsoil free of $CaCO_3$ 3. Pure brown earth, subsoil calcareous *(Secondary:)* Further classification not yet established	Further classification not yet established		1. Fully developed laterite profile B_2, B_1, $A_2(A_1)$, C 2. Incomplete B_1, $A_2(A_1)$, C 3. $A_2(A_1)$, C	Further classification not yet established	

Categories VI., VII. and VIII. as in Table XCVIII.

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TABLE CIII

PURELY MINERAL SOILS

I. Main group	II. Sub-group	III. Order	V. Main type
	7. Raw mineral soils	19. Soils of mixed rock débris	1. "Hamada" soils of the tropical deserts
			2. Frozen soils of the Arctic and snow regions
		20. Soils of mineral grits	Further classification not yet established
		21. Soils of fine dust	Further classification not yet established
	8. Mineral soils with some decomposition	22. The Ca of the mineral matter partly mobilised	
		23. The SiO_2 of the mineral matter partly mobilised	Further classification not yet established
	9. Mineral soils with the end-products of decomposition	24. Soils with salt crust easily soluble	
		25. Soils with salt crust slowly soluble	

Categories V., VI., VII. and VIII. not yet established because the available data are insufficient.

PART IV

PRINCIPLES OF SOIL CARTOGRAPHY

In the foregoing sections we have described the character of the soils forming the earth's outer crust; the last chapter of soil science deals with the natural laws governing the occurrence of the various soil types. This is no mere soil geography—no mere delineation by way of maps of the geographical distribution of soils. Soil maps are undoubtedly valuable auxiliaries of soil science, but from a pedological point of view it is not enough merely to delineate the distribution of different soils; we must at all times realise the true aim of soil maps. Ordnance maps very often serve as starting-points for soil maps. There may be soil maps the object of which is not pedological, but merely to establish property rights. There are maps, too, showing the soils as arable land, forests, swamps, etc., but they have no reference whatever to soil science.

Maps cannot possess the character and value of soil maps unless the *pedological* attributes of the soils are indicated. Without stressing the pedological basis we cannot even draft a real soil map, for we do not know what we have to delineate. To insist on the application of general pedological principles in drafting a soil map is to enhance the value of the map and to make it of more general interest.

In former times soil maps usually served mostly practical purposes; they delineated local soil occurrences from an agricultural or silvicultural point of view, characterising them solely on the basis of their physical properties and the plant-food conditions. This approximately corresponded to the principles given in the last two stages of my system, though the classification lacks all connection with a higher and more general grouping of soils. The intrinsic value of these soil maps was consequently limited to what might be called the practical interests of the community. A somewhat more general character belonged to those soil maps which were based upon geological surveys. In the light of modern science all that these maps succeeded in doing was to satisfy the practical and scientific interests of the particular region for which they were made, for in other regions with similar geological formations soils of an entirely different nature may be found. For that reason the introduction into soil cartography of soil types as independent natural formations has led to the invention of a new scientific technique. This technique has given us units of as general a character as those represented by rocks and geological formations in geology. The mapping of soil types then led to the discovery of soil zones and soil regions, paved the way towards the drafting of

general maps of the soil types of large areas, whole countries, continents and indeed of the whole globe.

The more extensive the territories embraced in a soil map, the smaller the scale that had to be adopted and the greater the indistinctness of local varieties, of regional types and indeed even of the main types not forming continuous zones. This naturally means that the more general the soil maps drafted, the higher the stage of my system to be adopted, until finally we reach the first stage, which divides all the soils of the world into three main groups. Thus, if we draft soil maps corresponding to a particular stage in my system, we may gradually extend or reduce their scope at will; if, for instance, we begin by marking Stage VI. only, we can gradually advance until we reach the highest stage (I.). Or, for instance, if on a soil map showing only the physical classification of soils we mark the soil types also, we thereby locate their positions in the general soil system.

But before entering into a full discussion of the principles of soil cartography, I must refer to another peculiarity of the geographical distribution of soils. Recently the Russian soil scientists have pointed out that even in regions in which soil types occur zonally, we may find not only soil types characteristic of that zone, but others as well. The latter are called intrazonal types or—where they occur independently of the climatic belts—azonal soils. Alkali soils, for instance, are usually found in the form of isolated islands in steppe soil zones; these soils are therefore intrazonal. Peat soils may, on the contrary, rightly be called azonal, because they occur in practically all zones.

This does not, however, by any means exhaust the question of varieties within the limits of the soil zones. Botanists often speak of plant associations. Soil zones also frequently constitute complex zones which embrace a certain association of several soil types. These complex zones develop chiefly at the points where adjacent zones meet.

All this is not merely accidental, but is the result of the variations of all the soil-forming factors concerned. Far-reaching changes may be caused in particular by the orographical and hydrographical conditions, by the struggle for existence of the vegetation, by the destruction of the fauna or by human culture. In other words, these heterogeneous occurrences and the succession of the zones are regulated by special natural laws the effects of which may be delineated—in addition to being shown on maps—by theoretical diagrams which are often more comprehensive than the maps themselves.

Thus soil cartography in the wider sense of the word includes, apart from the mere drafting of maps, other means—outlines, drawings and cross-sections—for illustrating the occurrence and distribution of soils, and generally describing their genetic and dynamic conditions.

CHAPTER XVI

VARIOUS TYPES OF SOIL MAPS

THE scope of soil maps depends upon the object in view. Two main groups can be distinguished—*general* and *special* maps. In both of these groups we may differentiate a very large variety of grades according to the scale of the map. The higher the soil category referred to, the more comprehensive the map and the smaller the scale required. A soil map embracing the whole globe is the most comprehensive and the most general of all maps.

Zonal soil maps cannot be regarded simply as climatic or phenological maps. The latter coincide slightly better with soil maps than do climatic charts. This is due to two reasons: (1) the natural vegetation itself is partly a function of the quality of the soil and partly of the climatic conditions, and (2) since no general pedological survey has yet been made to include the whole world, world maps are in many of their details not true soil maps at all, but have been drafted on the basis of phenological data. Especially defective are the soil maps of continents the soil conditions of which cannot be determined yet—owing to the lack of human culture—except on the basis of superficial travel books.

For obvious reasons, the natural order of things would be first to make exhaustive soil surveys of the several districts and countries, followed by the drafting of comprehensive maps based on the higher categories of the soil system. Any gaps and mistakes in local surveys would tend to be eliminated when the comprehensive map is being rafted.

That the International Society of Soil Science selected the opposite —unnatural—procedure, was due primarily to a desire to make the fundamental principles of the Russian school familiar to soil scientists the world over and to persuade them to adopt those principles. The scheme has proved partly successful. The general soil map of Europe drafted by STREMME, with the collaboration of a large number of soil experts, for instance, has really shown that the soil types are a suitable basis for a general and comprehensive map of soil occurrences, and that those types as a whole conform not so much to the parent rock as to the natural vegetation and the prevailing climate. STREMME'S map showed also that soil types which in the vast Russian Empire form extensive and continuous soil zones occur in those parts of Europe where the orographical and climatic conditions show more variety, in certain regions but not in continuous zones. It may happen, however, that zonal soil types occur sporadically and form neither

zones nor regions. For the soil cartographer these local occurrences are of importance only on local maps.

Since the soil types occupying extensive territories have proved a suitable basis for constructing comprehensive soil maps, while the soil zones often correspond more or less exactly to the climatic zones, maps of this kind are often called "*climazonal*" *soil maps*. It should be noted, however, that this term is often misleading, and it would be better on all occasions to express the unit or stage of the soil system to be shown on the map.

In order to illustrate this principle I shall discuss in more detail the general soil map of Europe drafted by STREMME,* who uses a term invented by MIKLASZEWSKI, and calls his map a "Bodenentstehungs-typenkarte" because the origin of the soil types shown on it depends closely upon the principal soil-forming factors. The scale of the map is 1 : 10,000,000. The "legend" comprises twenty-seven signs, which do not all, however, denote separate soil types, for in transition areas we often find a combination of adjacent types. And there are other soil regions which are naturally composed of divergent soil types. In an explanatory note STREMME observes that in terms of a resolution of the meeting of Commission V. of the International Society of Soil Science held in Budapest (1926) the classification of the soil types shown on the map has been omitted, lest it should erroneously be assumed that the International Society of Soil Science had adopted a definitive system of soil classification. Undoubtedly this is a serious drawback; and with the object of supplying the deficiency the explanatory text to the map† did actually put the soil types shown into groups, adding, however, that the classification thus given did not claim to be regarded as a soil system. STREMME's grouping is as follows:

(1) Types of the great plant associations—semi-desert steppe soils, tshernosems, forest soils, dry forest soils, tundra soils, possibly some red earths (?). Climatic peculiarity: raw-humus occurrence.

(2) Types showing counteraction of parent rock — rendzinas and degraded rendzinas.

(3) Soil types produced by water accumulation—peat soils, peaty tshernosems, marsh soils formed in valleys and on the banks of rivers or on the seashore, saline soils.

(4) Soil types of mountainous regions—skeletal soils, or mountain soils rich in skeletal soils.

(5) Deforested soil types of dry mountain regions—Karst and Calvero soils.

It is interesting to ascertain in which of the soil categories represented in our soil system we may include the twenty-seven soil types shown in the map.

* See "Allgemeine Bodenkarte Europas" der Unterkommission f. d. Boden-karte Europas, bei der V. Kommission d. Intern. Bodenkundlichen Gesell-schaft. *Erläuterung* zur Bodenkarte v. H. STREMME.

† *Ibid.*

We find the following main types:

(1) Grey and brown steppe soils   ..   .. ⎫
(2) Chestnut steppe soils   ..   ..   .. ⎪
(3) Tshernosems   ..   .. ⎬ Ca soil order.
(4) Rendzinas ..   .. ⎪
(5) Calvero soils   ..   .. ⎭
(6) Littoral salty peat soils ..   ..   ..
(7) Alluvial soils   ..   ..

And the following sub-types:

(1) Brown forest soils ..   .. ⎫
(2) Grey forest soils   ..   .. ⎬ H soil order.
(3) Podsolic forest soils   ..   ..   .. ⎪
(4) Degraded tshernosems   ..   ..   .. ⎭

The last-named includes three sub-types of degraded calcium soils, and is therefore neither a sub-type nor a main type.

If we investigate the distribution of these main and sub-types—*i.e.*, the calcium and hydrogen soil orders—as shown on the general soil map, we shall see that these form the bulk of European soils. The total area covered by all the other types shown on the map is not so large, nor do they individually occupy any large continuous territories. Even where the marking on the map appears to denote an extensive area, this is due to the marking showing a combination of various soils.

Mixed occurrences of this kind are the following: ·

(1) Tshernosem and degraded tshernosem, in the boundary territory between the two zones (" Vorsteppe ").

(2) Rendzina, degraded rendzina and podsolic forest soil (grey forest soil).

(3) Forest zones, in which the proportion of peat soil exceeds 40 per cent.

(4) Immature soils of mountain regions mixed with various other soils. The areas in question are shown on the map separately according to the quality of these other soils. The soils in this category are all skeletal soils sporadically mingled with one or other of the following types:

(*a*) Podsolic forest soils.
(*b*) Rendzinas.
(*c*) Red earths.
(*d*) Red earths and Calvero soils.
(*e*) Brown earths and Calvero soils.

The signs used on the map include also three soil orders, viz.:

(1) Saline and alkali soils—*i.e.*, the sodium soil order.

(2) The frozen soils o tundras—*i.e.*, soil order 8 (ectoadynamic soils of mixed origin

(3) Red earths

The extensive, continuous peat and swampy areas have been indicated with one and the same sign regardless of the differences between the various orders of this sub-group.

Further, among the podsolic soils we find what was then regarded as a strange definition. This referred to those podsols which have been truncated by erosion and which are called "truncated forest soils"—Main Type 4 of Soil Order 10 of my system.

But there is another definition which is not commonly understood—the term "swamp tshernosem," denoting a tshernosem formed in a swamp. We find a similar definition in KOSSOVITCH's monograph. I do not know how far the two definitions coincide, because we have no explanatory notes. However, in view of the fact that KOSSOVITCH alludes to the wet depressions of semi-arid steppes, whereas the patches shown on the map are all in forest zones, what STREMME refers to are probably swampy forest soils. These latter belong either among the wet meadow soils or among turfy or peaty mineral soils—both being main types of the hydrogen soil order. The soils mentioned by KOSSOVITCH, on the other hand, may be either black meadow clay soils or tshernosem patches occurring sporadically on the boundary line between a dry steppe zone and a tshernosem zone. The latter are genetically and dynamically calcium soils, the former degraded calcium soils—i.e., hydrogen soils.

Summarising the soil types shown on the general soil map of Europe, we find the following soil categories:

> 3 soil orders,
> 8 main types,
> 4 sub-types,
> 9 complex zones of mixed types,
> 1 complex zone of mixed soil orders,

and finally a further designation showing the frequency of occurrence of certain local types—e.g., of forest soils with here and there thick raw-humus layers. This is a transition in the direction of peat formation, which is very frequent in wet forest areas.

In general the map comprises soil categories included in the several stages of my soil system. It may, however, be noted that local varieties are almost entirely excluded. The fact that there are soil orders, main types and sub-types—i.e., three different stages of categories—is due to our not yet having a generally accepted soil system, while the various recent soil systems group the soil types from various points of view. But natural conditions also lead to a confounding of the categories, since soil maps can only show soil occurrences extensive enough to be marked on the map scale used. In particular, it is often impossible to indicate separately azonal and intrazonal types. On such occasions recourse is had to designating complex zones or to the use of special signs denoting the sporadic occurrence of other soil types within individual zones.

This naturally results in soil units belonging to different soil categories having to be marked together on one and the same soil map. In order to ascertain how far the general soil system explained in my book is applicable to a general soil map of Europe, my assistant (Dr. Kotzmann) and I have drafted—on the basis of Stremme's " Bodenentstehungstypenkarte "—a comprehensive general map of Europe, showing the soil orders, main types and sub-types of that Continent (Supplement II.). The map was enlarged and coloured for exhibition at the Third International Congress of Soil Science at Oxford in 1935, and has been reproduced for the present volume on a reduced scale in keeping with the size of the book.

In Supplement II. we find the soil items of Stremme's original soil map grouped as follows:

(1) Raw and humified organic soils: the extensive swampy areas to be found in particular in Poland, where in the Pripjet district they form a continuous territory of enormous extent, and, on a smaller scale, also in Holland and Germany. The original survey did not differentiate between turf and peat soils, nor did it give any information as to the kind of turf or peat soil respectively. For this reason we have been able to mark only the highest stage of our system. The group here designated is therefore Main Group I. of Stage I. of our soil system—viz., organic soils.

All the other soil occurrences shown belong to the main group of soils of mixed origin—i.e., to Main Group II. The first three subgroups of this main group—viz., the immature or skeleton soils, the humo-siallitic soils and the ferri-siallitic soils—occur very frequently on the soil map of Europe. The immature soils of mixed origin are to be found almost everywhere in mountainous regions, being sporadically mixed with soil orders, main types and sub-types corresponding to the geographical position. Hence these occurrences had to be included in the *complex soil zones*. As contrasted with the other complex zones these occurrences are shown in white. These skeleton soils are mostly ectoadynamic soils, only the young alluvial and marsh soils belonging to the order of pseudoadynamic soils.

The well-developed soil orders of Europe which cover extensive and coherent territories all belong to Sub-Group 2 of Main Group II.— viz., to the humo-siallitic soils. Ferri-siallitic soils are only found to any extent on the shores of the Mediterranean, while practically no occurrences of allitic soils are indicated.

We may now proceed to deal with the distribution of the several soil orders. Excluding the complex zones, the three well-developed soil orders occurring on the soil map of Europe are the hydrogen soils, the calcium soils and the red earths. On this map the brown earths of Ramann are probably confounded with the brown forest soils, the result being that the map does not show any true brown earths, while the area occupied by the hydrogen soil order has been increased

accordingly. The basic colour of hydrogen soils and red earths is light grey, of calcium soils dark grey. We can see at a glance that the area occupied by calcium soils in Europe is much smaller than that occupied by hydrogen soils. It is only in South France that the map shows any considerable area of continuous red earth. We see also that the occurrence of red earth mixed with skeletal soils is also confined to the Mediterranean shores of the southern States. The latter territories may therefore be included genetically and dynamically in the zone of red earths, the only reason why red earths do not form continuous areas being that they are prevented from doing so by the altitude. It should be noted, however, that on the Dalmatian coast and on the Italian Riviera the prevailing soil order is that of red earths —an occurrence which is also found (and marked on the map) on the French Riviera. If we exclude the skeletal soils of the mountainous regions, we find that the north, west and central parts of Europe are covered almost exclusively by the hydrogen soil order, only the southeastern part of Russia forming a coherent calcium soil order zone. There are sporadic islands in Poland, Rumania, Hungary, Bohemia and the Iberian Peninsula. The dark spots shown on the map denote these sporadic islands.

In our designation of the main types and sub-types we have retained STREMME's original markings, which are easily distinguishable from the basic colours of the soil orders. On STREMME's map we find only the main types of the calcium soil order, which are shown on our map as soils 2, 3, 4, 5, 6 and 7. The sub-types of these main types are not shown on the original map either. In the case of the hydrogen soils the original map shows mostly the sub-types only, which we have grouped in the following main types: degraded calcium soils, common forest soils and wet meadow soils. Degraded calcium soils have been subdivided into degraded tshernosems (8), degraded rendzinas (9), and swampy steppe soils (10). Common forest soils include brown forest soils (11), grey forest soils (12), podsolic forest soils (13) and truncated forest soils (14). We should, however, certainly include in the forest soil area also soil item 17, which represents the forest soils rich in raw humus, and soil item 18, which includes all the forest soils in which the proportion of peat exceeds 40 per cent.

The only wet meadow soils shown are those of the tundras (15). We know, however, that—particularly in the over-humid forest areas of the north, where there is an abundance of peat and raw humus— wet meadows are common. For that reason complex zones 17 and 18 also belong here.

Soil item 19 includes the various sodium soils of sporadic occurrence. These are typically intrazonal soils occurring in various soil zones but most frequently found among the brown and grey steppe soils.

Although sodium soils are found also in the humid zones, particularly in marsh soil (27) regions, their distribution is so slight that the occurrences are not shown at all on the map. What we know of these

soils today is so little that this may be one reason why cartographers have taken no notice of them.

From what has been said, it will be seen that the application of our soil system enhances the value of a general soil map of Europe — particularly if that map is drafted on a large scale and in colours, as was my soil map of Europe presented to the International Congress of Soil Science in 1935—for the new map shows the laws governing the distribution of soil zones much better than the original map drafted by STREMME, and eliminates the want of system which was the chief defect of his map. Our new map may also be taken as an example of the possibility of showing on a single map units belonging to divergent categories of soils without prejudicing the principles of soil systematics.

General soil maps are intended to show the types of soil occurrences on large areas. Special soil maps, on the contrary, show in as detailed a manner as possible local occurrences and are intended to fix their extent with the utmost possible exactness. Many special soil maps of this kind have been drafted in all European countries and in the United States of America. As an illustration of this kind of soil map I shall refer to the special soil map of Thayer County,* Nebraska, U.S.A., which, while conforming to the survey system of the Bureau of Soils and treating the local occurrences by soil series, being drafted expressly for the purpose of practical agriculture, nevertheless *shows the influence of the Russian school in its description of profiles*, and therefore tallies with MARBUT'S soil system.

The soil map shows altogether twenty-nine soil series (local soil types), the respective areas of which are shown in Table CIV.

The first thing shown by the above data is that we are dealing with an accurate land survey such as cannot be demanded from general soil maps, if only because the latter—as we have seen—can show only the dominant types or soil orders. On a general soil map of Thayer County, for instance, not more than one, or at most two, soil types could be shown; for, as a glance at Table CIV. will show, the Crete silt loam and the Hastings silt loam form 74·4 per cent. of the whole territory, none of the other soils representing a proportion of even 10 per cent., and most of them covering only 1 to 2 per cent. Occurrences of such a slight extent would have to be omitted merely on account of the small scale of a general soil map. And in any case all these soils—if we omit the young alluvial and partly peaty soils—belong, as described, to one single main type of my system, viz. that of *prairie soils*. That is at least what both the external characteristics of the soils and the character of the cultivated crops and the original prairie vegetation would lead us to suppose. Passing over the difference of opinion between the Russian and the American

* See NIESCHMIDT, C. A., LOVALD, R. H., GEMMEL, R. L., and ROBERTS, R. C.: "Soil Survey of Thayer County, Nebraska" (U.S. Dept. Agric. Bur. Chem. and Soils Series, No. 20, 1927).

TABLE CIV

ACREAGE AND PROPORTIONATE EXTENT OF THE SOILS MAPPED IN
THAYER COUNTY, NEBR.

Type of Soil.	Acres.	Per Cent.
Crete silt loam	133,760	36·3
Hastings silt loam	92,160	28·1
Eroded phase	11,392	
Thayer silt loam	4,224	1·1
Pawnee silt loam	576	0·2
Nuckolls silt loam	21,312	7·1
Light-coloured subsoil phase	4,736	
Nuckolls loam	12,416	3·4
Lancaster fine sandy loam	128	0·1
Sogn silt loam	3,456	0·9
Shelby fine sandy loam	8,768	2·4
Shelby very fine sandy loam	5,952	1·6
Shelby gravelly loamy sand	3,008	0·8
Butler silt loam	9,856	2·7
Scott silt loam	1,408	0·4
Waukesha silt loam	14,784	4·0
Waukesha very fine sandy loam	5,440	1·5
Hall very fine sandy loam	5,184	1·4
Judson very fine sandy loam	2,112	0·6
Judson fine sandy loam	1,152	0·3
Wabash silt loam	5,824	1·6
Wabash very fine sandy loam	832	0·2
Lamoure silt loam	3,264	0·9
O'Neil very fine sandy loam	4,224	1·1
O'Neil sandy loam	1,280	0·4
O'Neil sand, light-coloured phase	192	0·1
Cass fine sandy loam	9,344	2·5
Cass silt loam	832	0·2
Sarpy sand	384	0·1
Total	368,000	

schools of soil scientists in respect of genetic explanation and of determination, we may say that most of these soils are true " prairie soils," the local varieties of which may show very instructive differences.

There is a very characteristic divergence between the two dominant local types. In both, the surface horizon is black earth of a crumby structure. The subsoil of the Crete silt loam is about 14-18 inches thick and contains an impervious brown clay pan which prevents the circulation of water in both directions. The next horizon is silt with a floury coating which is rich in lime; but it is inaccessible to the plant roots, since the clay pan is impermeable. Hence the plants must depend exclusively upon the water reserve and stock of plant foods stored above the clay pan. This soil is suited primarily for wheat-growing, being not so favourable to the growth of maize, which

needs abundant water in the late summer months (July, August). If the distribution of the rainfall in any particular year is not specially favourable, the maize crop suffers from drought, because the clay pan prevents the storing of the rain water in the lower horizons, while in the warm, dry summer period the moisture in the upper horizon evaporates very quickly.

In the subsoil of the Hastings silt loam there is no such compact clay layer, so that the plant roots and moisture are able to penetrate farther down, while in the dry seasons the vegetation is able to obtain the water it needs from a greater depth. The yield of maize is here less uncertain than in the case of the previous type.

Both these principal soil formations occur on plateaus situated on the average at a height of about 1,600 feet above sea-level. The plateaus are, however, split up into sections by deep rivers and streams. The soils formed on the valley slopes show varying stages of erosion. Without entering into details I will merely point out that some of these soils are varieties of Crete and others varieties of Hastings silt loam. Their fertility varies with the extent to which erosion has washed away the upper horizon.

In the depressions of various sizes found on the plateaus—depressions in which the ground water often accumulates to such an extent that in exceptionally rainy seasons the whole surface layer is under water —are found already degraded prairie soils. These are probably formations resembling the black meadow clay of the Hungarian lowlands. Finally, in the river valleys there are also various kinds of alluvial soils. These are indeed still young, but they are usually very fertile, for their basic material is the humous soil washed down from the sides of the plateau, while the humidity conditions are for the most part extremely favourable for growing both maize and alfalfa. Here the shortage of water due to the dry seasons is abundantly compensated for—naturally in addition to the ordinary rainfall—both by the surplus surface water flowing down from higher districts and by the ground water percolating flankwise from the rivers. Here and there the great abundance of humidity causes the formation of peat; but roughly 85 per cent. of the alluvial soils are under agricultural cultivation.

This brief description suffices to show that the soil map in question serves principally the interests of agricultural production; for, as we see, the characterisation of the soils itself tends to show primarily from an agricultural point of view for which branches of production the different local occurrences are best suited. No data of mechanical or chemical analysis have been given. All we learn about the physical properties, after studying the designations of the various soils, is that most of the soils are silty or sandy clays and are therefore admirably suited for agricultural cultivation. And since they are varieties of the prairie soil type, which is naturally a rich soil, the soils may in general be described as rich, unless the fertile layer has been entirely

washed away by erosion or unless the good properties of the soil are neutralised by unfavourable ground-water conditions (excessive or insufficient humidity). Of course it would be much better even from the practical point of view if we had figures enabling us to compare the respective plant-food conditions of the various soils. Another disadvantage is that we have not the chemical analysis of a profile of each of the principal occurrences, since without such analysis it is impossible to ascertain infallibly to which main type or sub-type the various local varieties belong and therefore in which soil order they are to be included. The soil structure described in general terms very closely resembles that of degraded tshernosems. The fact that in many local types we find in the subsoil a compact clay layer also allows us to assume that we are dealing with a degraded calcium soil. But none of these questions can be decided definitively without adequate profile descriptions and soil analyses. The absorbing complex and its degree of saturation would be guiding factors in deciding whether the soils are calcium or hydrogen soils. It is, however, indubitable that even where they are now hydrogen soils, they were originally calcium soils, for the surface soil is for the most part just as crumbly in structure as are tshernosems. Now, if these are really degraded calcium soils, it would be interesting to know what was the cause of the degradation; for according to American botanists prairie soils were never under forest. In that case the degradation may have been caused by a temporary excessive height of the water table—as is actually the case with some swampy soils with a permanently high water table. It would not be appropriate to enter into an exhaustive discussion of this special soil map, so I have confined myself to pointing out its advantages and disadvantages. In my opinion a special soil map should show the distribution of local types, their physical and physiological classification—i.e., the last three stages (VI., VII., VIII.) of my general soil system—in detail, giving exact acreages.

These are the principles on the basis of which local special soil maps have been drafted by STREMME; examples of this type of special soil map are those illustrating local soil conditions in the neighbourhood of Pietzkendorf near Danzig. I do not propose to discuss these maps here in detail; it will suffice to know how and for what purpose they were drafted. For details I would refer my readers to the original publication on the subject.*

According to STREMME the first thing to do is to draft a basal soil map which will show the local type of soil, its petrographic origin, lime condition and other physical characteristics, some properties of the surface horizon, the present mode of utilisation, its local name and finally the soil valuation expressed in the special figures adopted by him. As regards these figures we are given very little information in STREMME'S description; all we see is that the most valuable soil

* See STREMME, H.: "Die bodenkundliche Landesaufnahme in Dantzig" (BLANCK'S "Handbuch," Vol. X., p. 422).

type in Danzig is marked 100, the index figures of the other soil types being expressed in percentages.

By way of illustration I reproduce STREMME's table (CV.), which shows the average yields of the various plants for the cultivation of which the various soil types are best suited, and expresses the corresponding relative capability figure. The data do not embrace all the twenty-nine soil types shown on the map. The reason why STREMME included in his table only fourteen soil types is that the rest are either not cultivated at all or are soils for which no yield data are available.

From the table it will be seen that the method of soil valuation employed by STREMME was first to ascertain the average yields of the several types and then to calculate for each soil type the average soil value in percentages of the largest yields. The same methods had been employed previously by DOCUCHAIEV and SIBIRTZEV when fixing the values of the soils of the Government of Nishninovgorod (1882-6).* This method of soil assessment was also employed by GLINKA (1900-2) when calculating the soil values of the seventeen Governments of European Russia (surveying roughly 1,000,000 sq. km. of land). GLINKA also—between 1908 and 1914—surveyed some 3,000,000 sq. km. of land in Siberia, another 350,000 sq. km. being surveyed by the so-called Khazan Commission. Thus, even prior to the Great War this method of soil assessment had been tested over a very extensive territory in Russia.

It would be more reasonable and more equitable that the assessment of land taxes should be based upon such soil surveys.

For myself, I cannot accept as completely satisfactory in any respect the above method of valuation: for *the intrinsic value of a soil is not expressed fully by its average yield.* In addition to ascertaining the average annual yields of the various soil types, these soil surveys should also enable us to determine *the primary costs* of the average yields, together with the aggregate revenue obtained and the net profit secured. No doubt these values fluctuate, and to all appearances do not affect the intrinsic value of the soil. But *the yield depends not only on the quality of the soil, but also on the other factors of production.* These different factors cannot be reduced to a common denominator except by *expressing each factor in money.*

Every soil valuation must rest, however, on *precisely determinable properties of the soil* which exercise a definite influence on crop yield. These properties may be summarised as follows:

(1) The dynamic character of the soil.
(2) The special characteristics of each local variety of a given soil type: local orographical, climatic and hydrographical conditions, petrographic origin and a precise description of the soil profile.

* See YARILOV, A. A.: " Brief Review of the Progress of Applied Soil Science in U.S.S.R." (Leningrad, 1927).

TABLE CV

Average Yields in Quintals per Hectare.

Pedological Name of the Soil.	Local Name of the Soil.	Wheat.	Rye.	Barley.	Oats.	Peas.	Beans.	Rape.	Potatoes.	Sugar Beet.	Fodder Beet.	Turnips.	Clover Hay.	Lucerne Hay.	Meadow Hay.	Value of the Soil by Stremme's Assessment.
Turf soil	—	13	17	14·5	17·5	—	17·5	—	137	—	350	—	—	—	30·5	42-25
Turfy soil	—	24·5	23	21	26	—	25	—	158	190	400	—	—	—	42	63-50
Wet meadow soil	—	26	23	23·5	26	21	24	18·5	149	248	392	—	40·5	—	34·5	70-55
Cultivated forest soil	Niederungsboden	28	24·5	24	27·5	23	26	18·5	160	258	426	—	—	—	43·5	72-60
Brown forest soil with stagnant ground water	—	29·5	27	30	28·5	22	27·5	19·5	160	255	360	—	47·5	—	36	85-62
Forest soil changed into steppe soil	Oberwerdenboden	33·5	28	34·5	30·5	23·5	30	24·5	182	300	400	—	47·5	—	40·5	100-80
Brown forest soil of the hills	Niederhöheboden	25	21	26	26·5	20	—	17·5	175	230	440	325	64	145	75	85-65
The same, slightly podsolised	Übergangsboden der Mittelhöhe	16·5	14	16	17	—	—	—	140	—	—	210	39	—	32·5	65-45
Rust-coloured brown forest soil, slightly podsolised	Übergangsboden der Mittelhöhe	—	12	13·5	14·5	—	—	—	90	—	—	140	37	—	32	45-20
The same, strongly podsolised	Oberhöheboden	—	10	10·5	11·5	—	—	—	100	—	—	120	34	—	32·5	40-10
Alluvial sands and terraces	Prausterfelderboden	—	24	16	22	—	—	—	160	—	200	—	—	—	30	70-50
Meadow soils of the valleys	—	—	14	—	14·5	—	—	—	115	—	—	150	—	—	40	45-20
The same in good cultivation	—	24	21	25	28	—	—	—	165	200	300	325	—	—	—	65-50
Sands broken through by the Vistula River	—	21·5	22·5	20	25·5	15	18·5	—	143	—	300	—	—	—	35	35-18

(3) The following physical characteristics: (*a*) the texture of the soil (sand, loam, clay, etc.); (*b*) mechanical composition; (*c*) maximum water-holding capacity; (*d*) depth of living roots; (*e*) characterisation of water régime.

(4) The following physiological characteristics: *lime conditions,* pH value, hydrolytic acidity, unsaturation, alkalisation, etc., *humus content* (total and active), depth of humus horizon, stability of humus, etc.; *total plant food* (P, N and K, and also *the easily accessible reserve*).

If we have ascertained also the practical importance of these values, it will be possible to set the drafting of local special soil maps on a firm and reliable basis.

However, since a practical farmer is unable to make head or tail of complicated maps of the kind postulating much expert knowledge, separate practical maps must be prepared from the basal map. This is the purpose of the practical maps described by STREMME. In Danzig recently ten maps on a scale of 1 : 10,000 have been drafted for the area of each administrative unit for which surveys of the kind have been made. First two basal (geological and pedological) maps were made on the basis of the former three, and on that of the latter five other maps were drafted. Of the maps drafted from the data of the geological map one is concerned with the useful rocks, one with the water supply and one with the suitability of the various soils as house sites. Of those drafted from the pedological map one deals with the need for irrigation, one with the possibility of cultivation and with the quality of the crops produced, one with the need for lime, one with the need for farmyard manure and one with the need for artificial fertilisers. With the help of the auxiliary maps farmers are really enabled to obtain all the information they require in matters of interest to them; and that is what practical soil maps are intended to do.

Another great group of soil maps consists of those *special maps* which are drafted *for a single special purpose.* In principle, the only difference between them and the former category is that they deal with only one particular soil type—*e.g.*, alkali soil types. They may be comprehensive or local. The map showing the salt content of the Békéscsaba alkali land (Fig. 9), for instance, is a local soil map of this kind. Like all such maps, this soil map is entirely one-sided. What we wanted to ascertain from the survey at Békéscsaba was the distribution and kind of the salts in the irrigated alkali land in the third year of irrigation and the interdependence of vegetation and salt content.

I have also drafted a more comprehensive map of the districts flanking the proposed deep-cut canal connecting the Danube and the Tisza.* But the time available was not sufficient to enable me exactly to demarcate on the map the boundary lines between the

* See SIGMOND, E.: Szt. István Akad. Term. Tud. Oszt., Vol. I. (1926), No. 12.

various salt classes. On the map, therefore, I have not drawn any sharp lines of division—as shown in Supplement II.

In Denmark and Germany—and recently in Hungary too—soil maps have been drafted which show only the pH value of the soils. In districts in which the excessive height of the water level is injurious and it would seem expedient to drain the water, maps have often been drafted showing the height of the water level. We should do even better to supplement this work by ascertaining the minimum air capacity of the soil, its pore volume and absolute water capacity, by investigations on the spot, for that would enable us to tell where we may expect drainage to produce positive results. If we determined also the mechanical composition, we should be able in addition to calculate the most advantageous distance and depth at which to lay the drainpipes.

CHAPTER XVII

LAWS GOVERNING THE GEOGRAPHICAL DISTRIBUTION OF SOIL TYPES

IF we study closely the distribution of the soil types covering the earth's surface, we are struck by the fact that their occurrence is not merely accidental, but is causally connected with the environmental conditions. It was this fact that led to the "climazonal" or regional classification of soil types; for the climate is the external soil-forming factor which in combination with the natural vegetation practically determines the whole trend of soil formation. It is true, indeed, that other factors—e.g., the properties of the parent rock, and the local orographical and hydrographical conditions—often exert a modifying influence and counteract that of the climate; nevertheless, each climatic zone has its own peculiar or typical occurrences. Very instructive on this point is Vol. III. of BLANCK's "Handbuch." If we glance through the contents of this volume, we are struck at once with the fact that, although in each climatic zone we find several— and not merely one—soil types, the typical occurrences are neverthe- less to a certain extent functions of the respective climatic zones. It was this natural connection that led to the "climazonal" classifica- tion of the Russian school. In previous chapters of this book we have, however, repeatedly seen that within individual climatic zones we find occurring, not only the soil types characteristic of each zone, but also other soil types. Thus, when we describe a soil type as character- istic of a climatic zone, we do not thereby mean that no other soil types can be found within that zone. The essential point is that the occurrences are *not accidental* but are in every case *regular functions of the local soil-forming factors.*

Following BLANCK's distribution by climates, STREMME described as zonal occurrences in the cooler part of the temperate zone two soil types—viz., forest soils and brown earths. We know, however, that in the forest-soil zones rendzinas are formed on limestone parent rocks —soils which are calcium soils and are different from forest soils. Where the soil is water-logged, on the other hand, instead of forest soils we find turf or peat soils, turfy or peaty soils, or wet meadow soils. In the former case (that of rendzinas) the modification of the influence of the climatic zone is due to the limestone parent rock, and in the latter case to the local superabundance of water. For that reason it cannot be asserted that rendzinas or peaty occurrences are in these cases contrary to the laws governing soil occurrences. For in the former case the law operating is that in the formation of a rendzina the active lime content ($CaCO_3$) of the parent rock neutralises the acid medium, the result being that instead of a hydrogen soil we get a calcium soil. The occurrence of this soil is indeed not confined to any climatic zone, for rendzinas may be formed in all regions in which the external factors encourage acid leaching, while the parent rock is finely dispersed—active—lime. Nor can we assert that the formation of rendzinas is not influenced by the action of climate or vegetation; for the rendzinas of Poland probably differ from those of Spain or Java, just as the forest soils also include many sub-types which are the consequences of the interaction of climate and the other soil-forming factors. Since the decisive factor in the formation of rendzinas is the parent rock, while in the case of peaty soils it is the superabundance of soil humidity, these soil orders and soil types do not figure at all in Vol. III. of BLANCK's " Handbuch." The saline soils are also treated by BLANCK only as soil types peculiar to dry climates; but there is not a word about the saline soils occurring both in humid and tropical climates, which are local formations. They are usually found in littoral regions. A cardinal defect of " climazonal " classification is indeed that it does not systematically locate azonal or intrazonal soils. Another drawback of that system of classification is that it ignores that soil is not a function of climate only, but is *the joint product of all soil-forming factors*, so that, if I select only one or even two of the soil-forming factors (*e.g.*, climate and vegetation) as the basis of my classification, I am unable to fulfil the general requirement of classifying soil as a natural formation on the basis of the characteristics in evidence in it.

There is, however, also a great advantage attaching to the " climazonal " classification; for if we know the climatic zone we know what soil types may be expected to occur. Particularly instructive in this respect is, for instance, STEBUTT's diagram showing the order of succession of the soil zones in the east and west of Europe.* For, whereas in the west we pass from the northern podsolic zone through brown earths and red earths to the laterite zone, in the east the pod-

* See STEBUTT, A.: " Handb. d. allg. Bodenkunde," p. 363.

solic forest zone leads through the degraded tshernosems to the tsher-
nosems and then to the light-coloured steppe soils, ending in the south
in dry, hot deserts, the latter often without any transition blending
with laterites.

This order of succession of the soil zones does not, however, apply
to Europe only.   In the U.S.A., for instance, the order of succession
is also quite regular, though the climatic zones have developed differ-
ently in that country, so that the direction and order of succession of
the soil zones differ from those prevailing in Europe.   The order of
succession in the eastern part of the U.S.A. corresponds roughly to
that prevailing in Western Europe; it begins in the north with podsols,
passing into the zone of brown forest soils and then into the zones of
red and yellow earths, finally leading to the laterites of Florida.   When
we pass west from east, however, we find the brown forest soils leading
to the prairie soils and tshernosems, the latter being followed by chest-
nut and light-brown steppe soils, while finally beyond the Rocky
Mountains we find a grey-steppe soil belt.   Since, however, as we pass
westwards we find the zones forming belts running from north to south,
the differences in temperature in the several zones cause a further
progression of the main types ending in the north in podsolic soils,
and in the Gulf of Mexico in red earths or laterites.   This is shown in
outline by JENNY's general zonal soil map.*   Fig. 33 summarises the
ideal distribution of soil zones in Europe and North America respec-
tively (after STEBUTT).

The above diagram shows that in the eastern part of the U.S.A. —
along the Atlantic coast—the order of succession of the soil zones from
north to south tallies with that of the zones on the other side of the
Atlantic—viz., in Western Europe.   The north-south order of succes-
sion of the soil zones of Eastern Europe, on the contrary, is at right
angles to the previous direction.   The only exception to this rule is
that in the semi-arid zones we find prairie soils, which occupy a position
between the brown forest soils and the tshernosems.   In Russia this
position is occupied by degraded tshernosems or by a mixed zone of
steppe and forest soils, which the American prairie-soil zone very closely
resembles.†

Thus, the distribution of soil zones in the two continents again proves
that the occurrence of soil types is due to natural laws and is in causal
connection with the climatic conditions.

The regular succession of soil zones may also be illustrated by
means of a series of profile sections.   A series of this kind showing
the Russian soil zones has been drawn up by FILATOV,‡ while KOTZ-
MANN has done the same for the basin of the Great Hungarian Lowlands
(see Supplement III.).

* See JENNY, H.: Soil Research, Vol. I. (1929), p. 153.
† See FLOROV, N.: Soil Research, Vol. I. (1929), p. 200.
‡ See FILATOV, M. M.: " Diagrammatic Meridional Soil Profile of the European
Part of U.S.S.R." (Moscow, 1927).

The mountains of the west coast

Desert soils

Grey steppe soils

Light-brown steppe soils

Chestnut-coloured steppe soils

Tshernosems

Prairie soils

Laterites

Red and yellow earths

Brown earth

Podsolic soils

Northern part of the U.S.A.

East coast

Atlantic Ocean

West Europe

Red earths

Brown earths

North Europe

Podsolic soils

Laterites

Desert soils

Grey steppe soils

Light-brown steppe soils

Chestnut-coloured steppe soils

Tshernosems, Black steppe soils

Degraded tshernosems

Grey forest soils

East Europe

FIG. 33.—IDEAL DISTRIBUTION OF SOIL ZONES IN EUROPE AND NORTH AMERICA. (AFTER STIEBUTT.)

These sections have naturally been drafted on a small scale and are somewhat deformed, but they have been drafted in exact keeping with the actual pedological, geological, orographical and hydrographical conditions and show the natural vegetation which corresponds to the respective soil types.

The section drafted by KOTZMANN cuts through the Great Hungarian Lowlands in a W.N.W.-E.S.E. direction. It begins on the west with Mount Körös in the Bakony Range (713 metres), ending on the east at the Vlegyásza peak of the Bihar Mountains. The upper section shows the prevailing orographical conditions on a somewhat modified and reduced scale. Below is the soil profile section, based partly on TREITZ's soil map, partly on our own investigations. The profile section prepared by FILATOV cuts only the soil zones of the Great Russian Plain; the mountainous zones have been omitted, because the lack of space made it impossible to delineate the mountain regions faithfully and continuously. We endeavoured, however, to eliminate this difficulty by showing the characteristic profiles at heights corresponding roughly to the average altitudes of the respective regions. Our section does not therefore form a continuously connected reproduction; the various soil types are shown separately in profiles displaying their succession in plains and mountains. This method shows the soil types occurring along the soil section much more clearly and characteristically than the section drafted by FILATOV. Below each profile will be found the designation of the parent rock on which the soil rests, on the basis of the geological map given in DR. LÓCZY's (senior) " A Magyar Birodalom Földtani térkepe."

Beginning on the west, we find in the Bakony Range Upper Trias and Jurassic limestone alternating with freshwater deposits, while here and there we find Lower Cretaceous sandstone on the surface. Owing to the humidity of the climate, ordinary forest soils can form. Where the parent rock is not rich in lime, we find forest soils with a more or less eluviated podsolic horizon (A horizon) and a B horizon rich in iron. On the other hand, where the parent rock contains a large amount of active lime, we find rendzinas. Since the environs of Mount Körös consist of parent rock of the latter kind, our section begins with a rendzina, while as it passes east we find ordinary forest soils under mixed deciduous forests. Passing still farther east, in the less elevated downs (average height about 300 metres above sea-level) the subsoil is already loess, though its lime content is apparently not active enough to resist the effects of the more humid climate and to allow the formation of rendzina. Instead, we find slightly podsolic forest soils on which forests and meadow-land are mingled, and in the wetter parts black meadow clay soils. The granites of the Velence Hills (on the fringe of the Lowlands) are also covered with slightly eluviated forest soils. The height of the Lake of Velence brings our section to the level of the Great Lowlands and to the climatic region of the latter. From this point right as far as the Danube we find an alter-

nation of dark- or light-brown steppe soils and salty alkali soils respectively on subsoils of loess or marly clay.

Passing through the deposits of the inundation area of the Danube, we reach the sandy area between the Danube and the Tisza, which is mottled here and there—particularly in the parts near the Danube — by slightly turfy and "zsombik" areas. Next we find steppe soils alternating with salty alkali soils (soda soils) and peaty soils. In the heavier parts of the elevated sandy territory there are sandy steppe soils, in the looser parts drift-sand or artificially stabilised drift-sand. As we approach Czegléd and Tószeg we find sporadically on the banks of the Tisza larger connected areas of heavy "szik"-lands which consist partly of salty and partly of leached alkali soils (often with a characteristic columnar structure).

When we reach the inundation area of the Tisza we find that the predominant soil type is black meadow clay, followed by a large loess territory in which for the most part steppe soils have been formed. Somewhere just to the east of Mezőtur we find the black meadow clay alternating with leached or salty alkali and steppe soils, these persisting until we reach the downs of the Bihar mountain district. Here the loess for a considerable distance covers the hills; though—as a consequence of the more humid climatic conditions—from the loess, not steppe soils but slightly leached forest soils (probably degraded calcium soils) have been formed. Further on the section leads us through Upper Jura and Upper Trias limestones until we reach the rhyolite andesites of the environs of Vlegyásza. Here the soil formation shows that with the higher altitude the increasing humidity of the climate enhances the acid leaching—i.e., there is an increasing development of podsolisation. The region of mixed deciduous forests is followed first by a close deciduous forest and then by a close pine forest. The fact that we find a calcium soil (rendzina) in places even under forest is due to the parent rock being rich in lime.

The section shows that in general the soil types adjust themselves to the height of the respective regions, while the local occurrences are influenced partly by the parent rock and partly by the local orographical and hydrographical conditions.

There are cases in which the laws governing the soil occurrences may be shown more clearly by drawing in outline the ideal changes in the profiles. A drawing of this kind is the sketch by HARRASSO-WITZ entitled "Schematischer Überblick über die Verteilung der wichtigsten Bodentypen in den Tropen."*

According to this sketch the laws governing the distribution of tropical soils are as follows: In the constantly wet and equably hot tropics a genuine podsolisation takes place under the raw-humus cover of the tropical primeval forests. The result of this process is the following profile: an upper humus cover, below that a podsol horizon, iron concretions and brown or yellow clay. This is therefore

* See BLANCK's "Handbuch," Vol. III., p. 436.

the soil type of the zone of tropical primeval forests, a soil which, though it may differ in detail from the podsolic forest soils of the temperate zones, is to be regarded as identical with them dynamically and genetically. These are therefore tropical hydrogen soils, with unsaturated absorbing complexes, a surface humus cover, and eluviation with an accumulation horizon below.

The next zone is that of the monsoon forests, a zone which is only periodically rainy and in the intervals becomes quite dry. Here, as a consequence of the alternation of dry and wet periods, the humus cover decomposes completely and only the upper podsolic or yellow layer remains. This type passes into the red earths of the even drier savannahs. These merge almost imperceptibly into laterites—i.e., from siallitic to allitic soils. Here we find first siallitic laterites and then completely allitic laterites. Finally, as we approach the dry steppes, we find the laterites passing into crusty desert soils with lime concretions and practically bare of vegetation. From this ideal order of succession we see therefore how the soil of a primeval forest, impassable owing to its luxuriant vegetation, merges, with the gradual and periodical decrease of humidity, into soil types with vegetation becoming more and more scanty, and finally into the crusty and salty desert soils with no vegetation at all. Here the order of succession of soil types and soil orders is governed by the variation and distribution of humidity.

There are cases, however, in which we find various soil types and soil orders side by side under identical climatic conditions. This may be seen, for instance, in several districts of the Hungarian lowlands, where steppe soils are found alternating with black meadow clay soils and with " szik " soils. Despite the identity of climate there is nevertheless an alternation of soil types belonging to three different soil orders. This is due partly to the relief and partly to the local hydrographical conditions.

Where the surface of the Hungarian lowlands lies so high that it has never been exposed to periodical inundations, and the subsoil does not contain any impervious layer near the surface which might cause a high-water table, dark- or light-brown steppe soils have been formed in keeping with the semi-arid climate of that region. Where, however, the surface lies low, forming closed basins and depressions, and has been periodically or continuously covered with a shallow layer of water, " szik " soil or black meadow clays have been formed. The former soils have been formed where the periodical flooding alternated with a periodical drying of the soil, the downward migration of the salts being followed by an upward migration. But where the water cover was permanent there was a certain primitive peat formation. As a result of the draining-off of the surplus water, however, the primitive peat was transformed into black meadow clay, which is really a degraded calcium soil, only the degradation in this case is not due ultimately to an increase of forest vegetation, but to the effect of peat formation.

Though the differences between the various local orographical conditions are not considerable enough to influence materially the climate itself, nevertheless the " micro-relief " difference, combined with the changes in the water table, may bring about changes in the humidity and leaching conditions of the soil so considerable that in the first case a calcium, in the second case a sodium and in the third case a hydrogen soil has been formed.

Even more striking changes may be caused by large variations in the macro-relief, which affect not only the soil but also the climate and the vegetation. These changes are the cause of what are called mountain or vertical soil zones. They were first discovered by Docuchaiev when studying the Caucasus (1899). Glinka deals with three series of mountain-soil types.* A very interesting series, corresponding to the West European humid zone series, is also described by Jenny.† Though the details of mountain zones may vary, the order of succession of the zones is governed by general natural laws.

It is evident, therefore, that the occurrence of the various soil orders and soil types is *not accidental* but is always the result of the interaction of soil-forming factors. The examples given show also that the order of succession of the occurrences is regular and depends often on climate and equally often on local orographical and other conditions.

CHAPTER XVIII

TO WHAT EXTENT DOES THE ACTUAL DISTRIBUTION OF SOIL TYPES AGREE WITH THE GENERAL SOIL SYSTEM ?

When we examine more closely the general soil system discussed in the preceding section and investigate the distribution of the same and the several stages of soil groups, we find that there are definite connections between the order of succession and the conditions governing the formation of the various groups, orders and types.

When we compare the order of succession of the three main groups with the zones on the surface of the earth in which they are found, we see that the soils of the organic main group are not present except where for some reason or other there was originally a sufficient abundance of water to enable the hydrophyte vegetation itself to supply the bulk of the raw material of the soil. In these places, then, the soil was formed practically independently of the mineral part. For that reason soils belonging to this main group are only to be found where there is a possibility of the presence of an excess of water. There are two ways in which an excess of water may accumulate on the earth's

* See Glinka, K.: " Typen der Bodenbildung," p. 340.
† See Blanck's " Handbuch," Vol. III., pp. 117-18.

surface—either by the annual rainfall exceeding in volume the annual evaporation in places where there are impervious and enclosed basins, or by the level of the subsoil water for some reason or other being higher than the surface of the soil, the whole annual evaporation being insufficient to carry off the water thus accumulated. In both cases we have to deal with the effect of climate; the first, in particular, is the result of a humid—indeed, superhumid—climate. This explains why organic soils are found chiefly in humid zones and why they become rarer and rarer as we enter the more arid zones. Another *sine qua non* is that the temperature shall be high enough to enable a hydrophyte vegetation to thrive. In the arctic regions, for instance, where the earth's crust is frozen for almost the whole year, even in those rare periods in which the surface layer thaws slightly, the time is too short and the temperature too low to permit the development of organic soils. Hence the bulk of the turf and peat soils in Europe are found scattered about the boreal-forest zone of the north (Norway, Sweden, Denmark, etc.). When we reach the tundras, we find only turfy soils of mixed origin—*i.e.*, soils which, though formed in an excess of water, are, as a result of the low temperature prevailing, deficient in hydrophyte vegetation. In Europe, the further south we go, the warmer the climate, and a constant increase in the quantity of rainfall is required to secure an excess of moisture. As soon as we enter the dry, continental regions of South-East Europe—*e.g.*, the Russian steppes—we find a constant decrease in the area of organic soils, which are confined to places where an excess of ground water causes peat formation. Peat soils of this kind are not zonal, but azonal. They may be found even in the warmest tropics—*e.g.*, along the seashore or in the deltas of rivers. We see, therefore, that the formation of organic soils is the result of the action of two factors— an excess of water and a temperature favourable to hydrophytes. Consequently such soils are found zonally only in humid zones, though they may be found azonally or sporadically in all regions except icefields and dry deserts.

The second main group—viz., the soils of mixed mineral and organic origin—is to be found only where the moisture is insufficient to enable the hydrophyte vegetation to form soil unaided, though it suffices to encourage the development of higher plants, thus adding dead organic matter to the mineral material. Hence we find soils of mixed origin alike in the boreal, temperate, sub-tropical and tropical zones.

Pure mineral soils, on the other hand, are found either in dry deserts or in the arctic or snow zones, where the conditions essential to the development of organic vegetable life are absent.

To sum up, we may therefore say that the first and the third main groups are found chiefly in the extreme zones; while the soils found in the other zones mostly belong to the second main group—viz., to the group of soils of mixed origin.

In the following stage—in the sub-groups—we see a further differenti-

ation of soil distribution. At the very outset, in the organic soils, we find a difference—not only in degree of development, but also in the manner of distribution—between raw organic soils and humified organic soils. For there can be no doubt that a humified organic soil becomes peat soil through a certain decay of organic matter, depending partly on the age of development of the soil. Peats that are still living and growing are usually raw and only slightly humified and it is usually not until the peat has ceased growing that humification assumes significance. The activity and completeness of the process of humification increase with increase of temperature and of the quantity of air that finds its way among the dead plant residues. This is why more raw organic soils are found in cold regions than in warmer and drier climates.

When we pass to Sub-group 1 of the second main group—viz., the raw soils of mixed origin—we find that the continuity of distribution is interrupted, because these raw soils fall outside the recognised soil zones. They can be formed only in extreme deserts where, though the conditions necessary for the formation of organic matter are present, neither the organic nor the mineral matter suffers any sensible chemical change.

Taking the order of zonal succession, we find that the humified organic soils are followed by the humo-siallite soils. We might say that the latter are to be found in regions where both the conditions of humidity and the temperature favour a considerable chemical decomposition of both organic and mineral matter, though the process of decomposition is not complete enough immediately to form the end-products. This group includes most of the soils of temperate zones.

The next sub-group—the so-called ferri-siallite soils—are found in warmer (chiefly sub-tropical) zones which are periodically humid, and where the decay of organic substances is so active that we do not find any important accumulation of humus, while the decomposition of the silicates is not complete. In the case of the next—the sixth—sub-group this latter stage has been reached; indeed allite soils in general are found to contain the end-products of both organic and mineral matter. These soils are found only in the tropical zone—i.e., in a zone which is not only periodically humid but also very hot.

Finally, the soils in the three sub-groups of the third main group are found only in the azoic—i.e., desert—zones of the arid and torrid climates. So we encounter once more a considerable interruption in the continuity of soil formation, though in nature the allite soil region often immediately adjoins that of the desert soils. This is due to both regions belonging to the tropics, only the one belongs to the humid and the other to the arid, tropical zone. What we find depends upon the degree of aridity; we find either raw mineral soils or we may discover primitive traces of chemical decomposition. Sub-group 8 occurs in places where traces of silicate decomposition are already in evidence;

while Sub-group 9 occurs where there is periodically sufficient moisture to promote the accumulation of salts as the end-products of chemical decomposition and soil leaching.

This all shows us that the order of succession of the sub-groups is also closely connected with the distribution of the soils.

The laws of soil formation are illustrated even more perfectly by Stage III. of our soil system—viz., by the distribution of the soil orders. Soil Order No 1 is found chiefly in places where the excess of soil moisture results from excessive precipitation—viz., in superhumid climates or in mountainous districts. Order No. 2 occurs mostly in places where the surface is flooded by an abundance of ground water. It is not, however, confined to humid zones, being the result of local orographical and hydrographical conditions. Finally, the soils of Order No. 3 are formed—under the influence of saline water—in littoral regions. We find the same periodicity in Orders Nos. 4, 5, 6.

Order No. 7 is not dependent upon either climate or vegetation, but is entirely azonal. The soils belonging to this order are found in places where the parent material of the mineral part is resistant to any decomposition—e.g., quartz or other material strongly resistant to chemical weathering. The formation of soils belonging to this order results mostly from the action of geological conditions.

The reverse is true with Order No. 8, for, though the mineral part of the soil itself is liable to decomposition, the extreme climate (excessive constant cold or drought) prevents the development of soil dynamics. Hence this order is zonal, and is found in the arctic and snow zones or in dry deserts.

Order No. 9—the pseudoadynamic soils—contains soils to be found more or less in all climatic zones in places where running or stagnant waters bring into being fresh soil deposits. Though this order does not form coherent zones of any considerable extent, it is nevertheless of very frequent occurrence and covers very large areas in all. For this reason the order is of importance both from the pedological and the agricultural point of view.

Orders Nos. 10 and 11 comprise the bulk of the zonal soils of the temperate climate—the hydrogen soils embracing those of the humid and the calcium soils those of the arid temperate zone. The sodium soils (Order No. 12) do not form coherent soil zones, but are to be found chiefly in the form of islands in the calcium soil zones, being therefore typical intrazonal soils.

The distribution of Order No. 13—the brown earths proper—has not yet been definitely ascertained, for the difference between brown forest soil and brown earth has in many cases been left out of account, for which reason these two different kinds of soil are often quoted as one in statements relating to the distribution of soils. However, we find that the brown earths are confined to parts of the temperate zone in which the moist, cool season is followed by a warm and dry summer. In this respect the conditions resemble those governing the distribu-

tion of red earths, except that the latter require a warmer climate. As regards distribution there is a similarity also between the yellow earths and the brown and red earths. The difference probably lies in the chemical differences in the soil material; but at present our knowledge of this type of soil is too deficient to allow of our circumscribing the laws of distribution.

We thus come—through the yellow and red earths—to one of the most characteristic soil groups of the tropics—viz., allite soils. These are typical products of the humid tropical zone (alternating dry and hot seasons). The sub-tropical red earths are followed first by the siallitic allitic soils and then by the pure allite soils. Order No. 14 is therefore followed by Order 17, the next in succession being Order 16. In nature, however, as a consequence of the action of regional and local factors, this order of succession is not always in evidence. The essential laws governing the distribution of the other soils of the humid tropics have been known to us since the days of HARRASSOWITZ. Here I need only mention in addition Order No. 18, of which all we so far know for certain is that it does occur, though in default of exact data we are ignorant of the conditions and circumstances of its distribution. We may, however, note that the so-called bauxite-laterites owe their freedom from iron probably to the original mineral material itself having been free from iron.

Before leaving the group of soil orders of mixed origin, I must call attention to a characteristic feature of the distribution of the sodium soils and of Orders Nos. 13-18 respectively. Most of the Na soils—excluding the saline soils of humid regions—are found in places in dry and warm or temperately warm zones in which the soil periodically receives an excess of water. Soils belonging to Orders Nos. 13-18, on the other hand, are found in those places in humid climates where the wet seasons are interrupted by decidedly dry periods—i.e., where periodically the soils which otherwise contain sufficient humidity become very dry. Orders 13-18 are differentiated according to the rise in temperature from a temperate warmth to tropical heat. Yet there can be no doubt that, though there is a decided contrast, there is also a similarity between the respective circumstances governing the distribution of the latter orders and the sodium soils. The contrast is that, while Orders Nos. 13-18 belong to humid climates, the sodium soils—subject to the above restriction—are typical products of dry climates. In the case of both groups of soils, however, there must be an alternation of humid and dry soil conditions.

Finally, we have the Orders (Nos. 19-25) of soils of pure mineral origin. These are found zonally, in dry and hot deserts. They may, however, be found also in arctic and snow regions. The laws governing the distribution of the several orders of this main group are not zonal, but regional or local, depending either on the orography of the surface, on the intervention of periodical showers or on the infiltration of ground water. Consequently, Order No. 19 covers level surfaces

where the detritus of physical weathering cannot be sorted either by winds or by periodical showers. Orders Nos. 20 and 21 are mostly products of the sorting effect of winds. We have no detailed knowledge yet concerning the formation of Orders Nos. 22 and 23; but the pedogenic conditions allow us to conclude that they may be formed in regions where periodical showers (even if only for short intervals) induce a favourable weathering of the silicates and wash out the water-soluble salts. Orders Nos. 24 and 25, on the other hand, are found in deeper, closed basins in which the water collects, evaporating on the surface, or in which the seasonal rainfall, together with the dissolved salts, periodically comes to the surface in the form of ground water. The variety of the salts is probably due not so much to the external pedogenic factors as to the chemical nature of the parent rock.
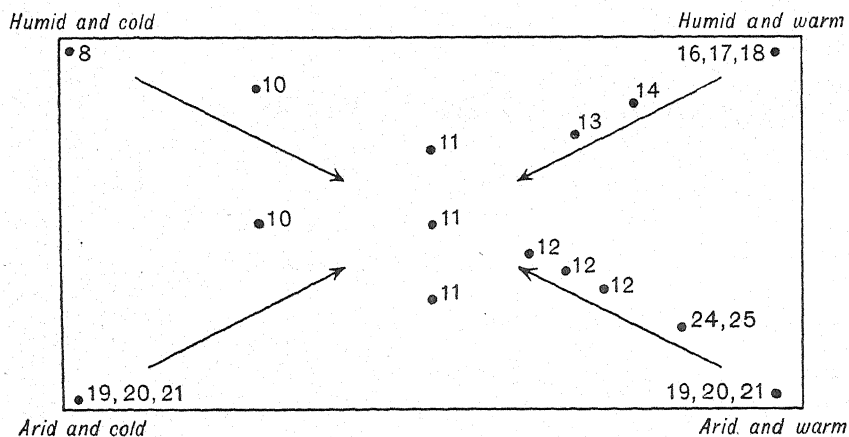
FIG. 34.

The distribution of the soil orders according to the changes in the two principal climatic factors—viz., humidity and temperature—is shown in Fig. 34.

The figures given above denote the numbers of the orders. The arrows show the centripetal movement of the various extreme climatic factors, which in the centre—in the zone of calcium soils (11)—become equipoised.

In the left upper corner of the parallelogram we find the ectoadynamic soil order (8), which leads through the hydrogen soils (10) to the calcium soils. In the left lower corner are the orders (19, 20 and 21) of the cold and dry deserts. These, too, lead through the hydrogen soils to the calcium soils. When we pass the calcium soils to the right, we again find a divergent series of soil orders. When we proceed in the direction of the right upper corner, we pass through the brown earths (13) and the red earths (14) to the various laterites (16, 17, 18). And when we proceed towards the right lower corner, we pass through

the sodium soils (12) and the soils with a salt crust (25), or pure mineral soils in an initial state of weathering to the pure mineral raw soils of the dry and hot deserts (19, 20, 21).

As we see, the order of succession and the circumstances of the distribution of the twenty-five soil orders contained in our soil system are closely connected with the typical characteristics of the several orders. Consequently, if we know the climatic or phenological conditions of the various regions or continents, our knowledge, combined with an application of the laws described above, should enable us to tell in advance what orders may be found in the territory in question. I would, however, emphasise that I am deliberately using the *conditional mood*. For, though these laws are derived directly from natural phenomena, nevertheless—since the formation of the soils is contributed to, not only by climatic and phenological factors, but also by other pedogenic factors—the climatic or phenological zones or regions do not always agree with the actual distribution. *Consequently, climatic and phenological charts cannot be simply redrawn unchanged as soil maps. The correct procedure is to base soil maps solely and exclusively on soil surveys ; for, as we have seen, several soil orders may be formed in one and the same zone.*

This is still truer of the main and sub-types or their local varieties — *i.e.*, of the units of Stages IV., V. and VI. of our system. Naturally I cannot enter into a detailed description of the distribution of each of the above units; for in the first place the space at my disposal is limited, while in the second place it is unnecessary, since, when dealing with the pedogenic conditions of each of the main and sub-types, I have already indicated the conditions or laws governing their distribution. Furthermore, in many cases we are not yet fully acquainted with the laws of distribution.

I shall confine myself to illustrating merely the regular order of succession of the best-known main and sub-types occurring zonally. Let us begin with the humid and cold zone, in which the soils are under the influence of an excess of humidity. This zone is the home of sphagnum turf and sphagnum peat, which, though they do not form large continuous zones, nevertheless impress their character on the soil zone of the region of superhumid and cool climates. Such, for instance, are most of the coniferous forest regions of Scandinavia. With decreased humidity we get peaty and turfy soils, which any further decrease of the surplus humidity converts into wet meadow soils. These are followed by common forest soils, which in the more humid regions are still slightly turfy or peaty, but with the decrease in humidity and the rise in temperature gradually turn into black steppe soils. The black steppe soils are followed by chestnut and light-brown and then by grey steppe soils; increasing aridity of the soil climate produces next in order desert soils with saline crusts and the raw soil types of arid deserts.

Parallel with the drier representatives of forest soils, but in warmer

regions, there develop primary brown earths and then *terra rossa*, these being followed in still warmer regions by siallites and then by common laterites. The other progression of soil zones begins with the black steppe soils and follows the other steppe soils until the grey steppe soils meet the arid desert soils with saline crusts.

The zonal order of succession is often followed also by the sub-types. Thus, for instance, in the case of forest soils the sub-types with a fully developed podsol horizon (A_2) are the more humid upper representative, the forest soils with a distinct A horizon are the middle representative, and those with no visible alluvial horizon the lowest, driest representative; they merge through the degraded steppe soils into the northern tshernosems $\left(\dfrac{A}{C}\right)$. The sub-types of the latter also constitute a gradual series passing through the thick central tshernosems to the zone of the southern tshernosems, as indicated in KOSSOVITCH's monograph.

Finally, I must warn my readers that even the great soil zones are composite—so-called *complex zones*—*i.e.*, in the same soil zone we find the main types accompanied by other soil types. In Vol. III. of BLANCK's manual, which deals with the distribution of soils in the various climatic zones, it is shown that almost all zones contain several soil orders, main types and sub-types. Similarly, the main types belonging to any single order occur in many different climatic zones.

The calcium soil order, for instance—the chief representative of which is the black or dark-brown steppe soil, such as the Russian tshernosem—is very widely distributed. It is found on the limit of the dry climate, where the latter meets the humid zone. We do not yet know for certain whether the second main type (prairie soils) should be included among the degraded calcium soils—*i.e.*, among the hydrogen soils. The latter probably require greater humidity for their development than do the tshernosems. A still greater humidity is required for the development of rendzinas. In Poland, for instance, the rendzina main type is found associated with podsolic forest soils. This is due to the resistance resulting from the active $CaCO_3$ content of the parent rock, which causes the rendzinas to be one of the most widely distributed soil types of calcareous rocks. We find rendzinas not only in humid warm climates but also in warm sub-tropical and tropical climates. We may therefore say that, while the steppe soils in general are the characteristic zonal main types of the temperate arid zones, the rendzinas carry the calcium soil order into practically all the zones in which the other conditions indispensable to the development of an abundance of continental vegetation are present in any form. From the inadequate descriptions available we may conclude that the fourth main type—the tropical and sub-tropical black earths—are to be regarded as calcium soils similar in character to the black steppe soils, but we are not yet sufficiently acquainted with their exact genetics

to be able accurately to determine their real place in the system or to define the conditions governing their distribution.

With Main Types 5 and 6 the calcium soils reach the limit of the saline soils of dry deserts. Main Type 7 in reality includes calcium soils obtained artificially from hydrogen soils. Finally, Main Type 8—the so-called " Calvero " soil—is really a pseudo-steppe soil type which began to develop in a manner similar to that of the rendzinas, but as a consequence of human intervention has assumed characteristics reminiscent of the light steppe soils. It is probable that in the course of time the calcium soil types will increase in number, for we are not yet fully familiar with these soils—particularly with the calcium soils of the warmer sub-tropical and tropical regions. But the conditions of distribution of the known types in themselves suffice to establish the fact that the calcium soil order may be found practically everywhere in the fertile regions of the world.

Equally widely distributed are the main types and sub-types of the hydrogen soil order. The very first main-type soils of this order— the turfy and peaty soils—which are found zonally only in the more humid and cooler climates, may occur azonally all over the world in places where the prevailing conditions are favourable to the development of hydrophyte vegetation. The same is true also of the wet meadow soils, which are found zonally or regionally only in humid and cool regions, but may occur everywhere associated with meadow peats, constituting a transition stage between waterlogged peaty soils and drier soils. The chief representatives of the hydrogen soils are the forest soils of the temperate zone. These soils often form well-developed zones or regions in a temperate climate, but, as we have seen, they are also to be found occasionally in tropical and sub-tropical districts covered by virgin forests. The descriptions available of Main Type 4—the truncated forest soils—are too inadequate to enable us to determine the conditions of their distribution. Finally, the degraded calcium soils are found on the junctions between forest soils (or, more generally, hydrogen soils) and calcium soils, thereby showing as it were the capacity of this essentially humid soil order to make headway in the more arid climates. Indeed, strictly speaking, it does not constitute a type of a single order; for its sub-types show that it may be formed from widely differing calcium soils. It is nevertheless convenient to class them all in one main type, since they are all hydrogen soils formed from calcium soils. Calcium soils of arid climates may also become hydrogen soils; but it should be noted that hydrogen soils derived from calcium soils are only found sporadically in the drier zones.

Far more widely distributed in drier climates are the sodium soils. This order of soils is far more widely spread over the the surface of the earth than we should suppose. For Main Type 1—the alkali-saline soils—is found not only in dry regions, but also in humid regions where for some reason or other the soil is saturated chiefly with solu-

tions of sodium salts. In particular, these soils are found in many low-lying littoral regions, irrespective of climate. The only exception is the region of eternal snow and ice. Nevertheless, the regions in which the alkali-saline soils are chiefly found are under arid climates, of which both this main type and the other sodium soils are characteristic products. HILGARD first showed that alkali soils are everywhere products of arid zones. GLINKA added that the alkali soils are the peat soils of arid climates—meaning that in humid climates the place of the alkali soils would be taken by peat soils. Indeed, most alkali soils are to be found, not in absolutely arid deserts, but in the sections of the arid zones (particularly of the steppe zones) periodically provided with an excess of water. This periodical excess of water originates, not from local precipitation, but either from water flowing down from higher levels or from inundations, or else from the periodical rising of ground water. Under such circumstances, in a humid climate, and where there is abundant precipitation and deficient evaporation, we should find peat developing into various kinds of turfy or peaty soil types. In the arid zones, however, the water evaporates on the surface and the sodium salts accumulate in the soil. This is the beginning of the alkalisation of the soil. The other sodium soil types are merely continuations of this process. The soil belonging to the first main type only deserves the name of sodium soil because it contains an unusual quantity of sodium salts. In the case of Main Type 2, however, the sodium penetrates into the absorbing complex of the soil and expels the calcium. Main Type 3 is found in places where the previous formation has been exposed to abundant leaching, so that the bulk of the sodium salts has been leached out into the lower horizons. In the case of Main Type 4, *i.e.* the degraded alkali soils, the leaching of the alkali soil has advanced so far, that the absorbed Na has been more or less replaced by H. Finally the degraded alkali soils are alkali soils which the alternation of the hydrological conditions has reconverted into saline soils. It is evident, therefore, that the development and distribution of the various types of alkali soils depend upon the local hydrological conditions. They are found in the low-lying closed basins of arid regions, in the closed inundation areas of rivers, and in the terrace formations of rivers situated at various altitudes. They have, however, developed everywhere at the cost of Ca soils; at any rate, we rarely find a sodium soil developing from a hydrogen soil. In principle it is not impossible, but it is probably a rare occurrence, for the zones of hydrogen soils are usually not suitable for the formation of sodium soils. The only exception is provided by the saline soils which develop in connection with the peat soils of littoral regions.

It will thus be seen that our system is very closely connected with the distribution of the several soil orders and types. This might have been anticipated, since the soil and its whole dynamic system are the results, not of chance, but of natural factors or factors deliberately

re-created by man.   The system rests on genetic and dynamic bases.

I have now brought to an end the theoretical part of my soil cartography.   The drawing of maps is the work of soil technology—as are soil analysis and the description of methods of investigation.

At the same time I have covered the purely scientific field of knowledge of soil science, summarising and systematising all that purely scientific knowledge and those purely scientific phenomena which are indispensable to a familiarity with the soil as an independent natural formation.

The application to practical life of this knowledge—as an applied science—stands in the same relation to general soil science as chemical technology to chemistry.   It might therefore be called applied soil science or soil technology.

SUBJECT INDEX

AUTHOR INDEX

Raw and
organic

Calcium

Hydrogen
Degraded ca

Ordinary for

Wet grassland

Red earth

Complex soil

Skeletal soi

Legend : 1. Raw and humified organic soils. 2. Grey and light brown " ste
soils. 3. Chestnut brown "steppe" soils. 4. Black and dark brown " ste
soils. 5. Tchernozem and degraded tchernozem. 6. Calvero soils. 7. Ren dz
8. Degraded "steppe" soils 9. Degraded rendzinas. 10. Degraded tcher nc
11. Brown forest soils. 12. Grey forest soils. 13. Strongly podsolised for
14. Denuded forest soils. 15. Tundra soils. 16. Red earths. 17. Forest s ils
raw humus spots. 18. Forest soils with more than 40% moor. 19. Zones
with sodium soils. 20. Skeletal soils with podsolised highland soils and ic
21. Skeletal soils with rendzinas and degraded rendzinas. 22. Skeletal soil
red earths. 23 Skeletal soils with red earths and calvero soils. 24. Skelet
with brown forest soils and red earths. 25 Skeletal soils with brown forest so
calvero soils. 26. "Marsch" soils. 27. Recent alluvial soils

**Distribution of the Soil Orders, Main- and Sub-
types in Europe.**

Based on the International Soil Map of Stremme.

Special Soil Map, showing the Distribution of Alkali Soils on the Left Bank of the Danube, surveyed by Dr. A. A. J. de Sigmond.

Total Salt Content.

Scale 1 : 300,000

I. 0–0·10%   II. 0·10–0·25%   III. 0·25–0·50%

PLATE II.
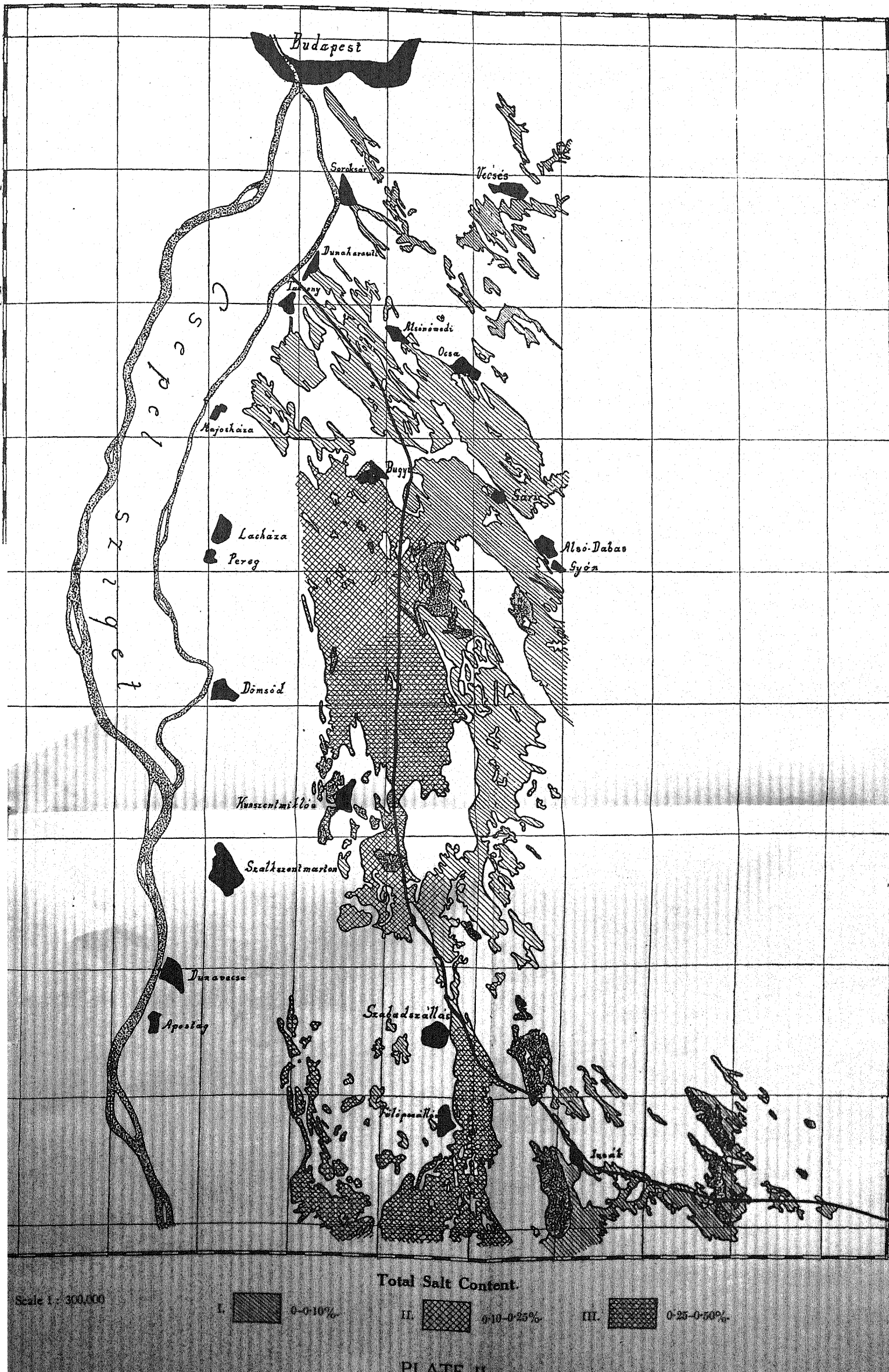
Schematic Representation of the Soils occurring along the Line between the Köröshegy (Bakony Mountains) and Vlegyásza (Bihari Mountains) across the Great Hungarian Plain.

Köröshegy 713 m

Vlegyásza 1848 m
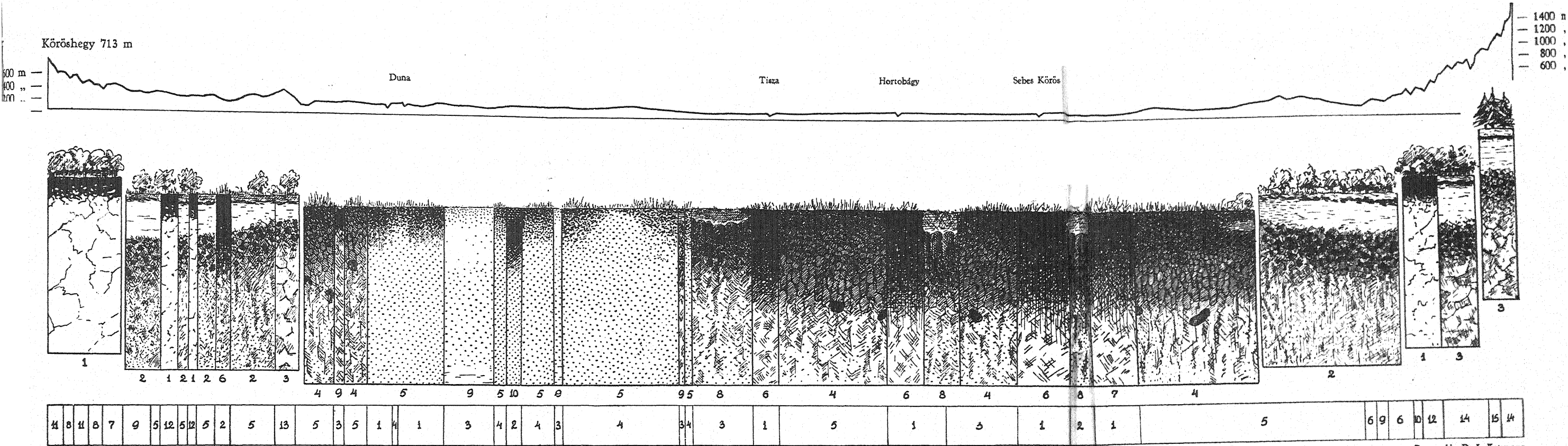
Prepared by Dr. L. Kotzmann.

Soil Profiles.

1. Rendzina soils; 2. Forest (podsolic) soils on loess; 3. Forest (podsolic) soils on hard rocks; 4. Black, dark brown or light brown " steppe " soils; 5. Sandy soils with more or less humus contamination; 6. Black, clay meadow soils; 7. Turfy mineral soils (" Kotu " soils); 8. Alkali soils poor in alkali salts (solonetz type); 9. Saline alkali soils (solontshak type); 10. Turfy and peat soils.

The Original Rocks.

1. Alluvial deposits; 2. Turf; 3-4. Holocene sand and clay; 5. Loess; 6. Pliocene sand and clay (marl); 7. Miocene sandstone and limestone; 8. Eocene limestone; 9. Lower Cretaceous sandstone; 10. Upper Jurassic limestone; 11. Lower Jurassic limestone and sandstone; 12. Triassic limestone and dolomite; 13. Granite; 14. Andesite, dacite, trachite, rhyolite; 15. Granodiorite.